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LESSONS

IN

ELEMENTARY PHYSIOLOGY.

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ELEMENTARY PHYSIOLOGY.

BY

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PREFACE TO REVISED EDITION,
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It is now more than twenty years since I planned and began to write these "Lessons," the object of which is defined in the preface to the first edition.

During this period physiological investigations have displayed an activity unprecedented in history. Here, as in all such branches of natural knowledge, the method of experiment has shown itself to be the one path which leads to truth, and has not only revealed multitudes of novel physiological facts, but has suggested wholly new lines of inquiry.

As successive editions of the "Lessons" have been demanded, it has been my effort to incorporate with them such solid acquisitions of the ever advancing science of physiology as fall within their scope, while rigorously excluding all debatable matter or, at any rate, carefully indicating it as such. At the same time, long experience as a Teacher and Examiner having forcibly brought home to my mind the difficulty

of making any statement that cannot be misunderstood, an amount of attention has been devoted to questions of mere exposition, which really deserves, but probably has not attained, the reward of abolishing such misunderstandings.

The present edition has been more extensively revised than any of its predecessors. The chapter on Histology, in particular, has been entirely reconstructed and provided with new illustrations, several of which have been taken from Ranvier and from Quain.

In the preface to former editions of this work, I have had the pleasure of expressing my obligations to Dr. Foster, Secretary to the Royal Society, for his very valuable assistance. That aid has been still more freely rendered to the present edition, which, in fact, could not have appeared unless Dr. Foster had taken upon himself the whole burden of seeing the work through the press. My friend has indeed done so much during my enforced idleness, that I should have been better satisfied if he would have permitted me to associate his name with mine on the title-page.

T. H. HUXLEY.

ROME, *February*, 1885.

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LESSONS

IN

ELEMENTARY PHYSIOLOGY.

LESSON I.

A GENERAL VIEW OF THE STRUCTURE AND FUNCTIONS OF THE HUMAN BODY.

1. THE body of a living man performs a great diversity of actions, some of which are quite obvious; others require more or less careful observation; and yet others can be detected only by the employment of the most delicate appliances of science.

Thus, some part of the body of a living man is plainly always in motion. Even in sleep, when the limbs, head, and eyelids may be still, the incessant rise and fall of the chest continue to remind us that we are viewing slumber and not death.

More careful observation, however, is needed to detect the motion of the heart; or the pulsation of the arteries; or the changes in the size of the pupil of the eye with varying light; or to ascertain that the air which is breathed out of the body is hotter and damper than the air which is taken in by breathing.

And lastly, when we try to ascertain what happens in the eye when that organ is adjusted to different distances:

or what in a nerve when it is excited: or of what materials flesh and blood are made: or in virtue of what mechanism it is that a sudden pain makes one start—we have to call into operation all the methods of inductive and deductive logic; all the resources of physics and chemistry; and all the delicacies of the art of experiment.

2. The sum of the facts and generalizations at which we arrive by these various modes of inquiry, be they simple or be they refined, concerning the actions of the body and the manner in which those actions are brought about, constitutes the science of Human Physiology. An elementary outline of this science, and of so much anatomy as is incidentally necessary, is the subject of the following Lessons; of which I shall devote the present to an account of so much of the structure and such of the actions (or, as they are technically called, "functions") of the body, as can be ascertained by easy observation; or might be so ascertained if the bodies of men were as easily procured, examined, and subjected to experiment, as those of animals.

3. Suppose a chamber with walls of ice, through which a current of pure ice-cold air passes; the walls of the chamber will of course remain unmelted.

Now, having weighed a healthy living man with great care, let him walk up and down the chamber for an hour. In doing this he will obviously exercise a great amount of mechanical force; as much, at least, as would be required to lift his weight as high and as often as he has raised himself at every step. But, in addition, a certain quantity of the ice will be melted, or converted into water; showing that the man has given off heat in abundance. Furthermore, if the air which enters the chamber be made to pass through lime-water, it will cause no cloudy white precipitate of carbonate of lime, because the quantity of carbonic acid in ordinary air is so small as to be inappreciable in this way. But if the air which passes out is made to take the same course, the lime-water will soon become milky, from the precipitation of carbonate of lime, showing the presence of carbonic acid, which, like the heat, is given off by the man.

Again, even if the air be quite dry as it enters the chamber (and the chamber be lined with some material so as to shut out all vapour from the melting ice walls), that which

is breathed out of the man, and that which is given off from his skin, will exhibit clouds of vapour; which vapour, therefore, is derived from the body.

After the expiration of the hour during which the experiment has lasted, let the man be released and weighed once more. He will be found to have lost weight.

Thus a living, active man, constantly exerts *mechanical force*, gives off *heat*, evolves *carbonic acid* and *water*, and undergoes a *loss of substance*.

4. Plainly, this state of things could not continue for an unlimited period, or the man would dwindle to nothing. But long before the effects of this gradual diminution of substance become apparent to a bystander, they are felt by the subject of the experiment in the form of the two imperious sensations called hunger and thirst. To still these cravings, to restore the weight of the body to its former amount, to enable it to continue giving out heat, water, and carbonic acid, at the same rate, for an indefinite period, it is absolutely necessary that the body should be supplied with each of three things, and with three only. These are, firstly, fresh air; secondly, drink—consisting of water in some shape or other, however much it may be adulterated; thirdly, food. That compound known to chemists as *proteid* matter, and which contains carbon, hydrogen, oxygen, and nitrogen, must form a part of this food, if it is to sustain life indefinitely; and fatty, starchy, or saccharine matters ought to be contained in the food, if it is to sustain life conveniently.

5. A certain proportion of the matter taken in as food either cannot be, or at any rate is not, used; and leaves the body, as *excrementitious matter*, having simply passed through the alimentary canal without undergoing much change, and without ever being incorporated into the actual substance of the body. But, under healthy conditions, and when only so much food as is necessary is taken, no important proportion of either proteid matter, or fat, or starchy or saccharine food, passes out of the body as such. Almost all real food leaves the body in the form either of *water*, or of *carbonic acid*, or of a third substance called *urea*, or of certain *saline* compounds.

Chemists have determined that these products which are thrown out of the body and are called *excretions*, contain

if taken altogether, far more oxygen than the food and water taken into the body. Now, the only possible source whence the body can obtain oxygen, except from food and water, is the air which surrounds it.[1] And careful investigation of the air which leaves the chamber in the imaginary experiment described above would show, not only that it has gained carbonic acid *from* the man, but that it has lost *oxygen* in equal or rather greater amount *to* him.

6. Thus, if a man is neither gaining nor losing weight, the sum of the weights of all the substances above enumerated which leaves the body ought to be exactly equal to the weight of the food and water which enter it, together with that of the oxygen which it absorbs from the air. And this is proved to be the case.

Hence it follows that a man in health, and "neither gaining nor losing flesh," is *incessantly* oxidating and wasting away, and *periodically* making good the loss. So that if, in his average condition, he could be confined in the scale-pan of a delicate spring balance, like that used for weighing letters, the scale-pan would descend at every meal, and ascend in the intervals, oscillating to equal distances on each side of the average position, which would never be maintained for longer than a few minutes. There is, therefore, no such thing as a stationary condition of the weight of the body, and what we call such is simply a condition of variation within narrow limits—a condition in which the gains and losses of the numerous daily transactions of the economy balance one another.

7. Suppose this diurnally-balanced physiological state to be reached, it can be maintained only so long as the quantity of the mechanical work done, and of heat, or other force evolved, remains absolutely unchanged.

Let such a physiologically-balanced man lift a heavy body from the ground, and the loss of weight which he would have undergone without that exertion will be immediately increased by a definite amount, which cannot be made good unless a proportionate amount of

[1] Fresh country air contains in every 100 parts nearly 21 of oxygen and 79 of nitrogen gas, together with a small fraction of a part of carbonic acid, a minute uncertain proportion of ammonia, and a variable quantity of watery vapour. (See Lesson IV. § 11.)

extra food be supplied to him. Let the temperature of the air fall, and the same result will occur, if his body remains as warm as before.

On the other hand, diminish his exertion and lower his production of heat, and either he will gain weight, or some of his food will remain unused.

Thus, in a properly nourished man, a stream of food is constantly entering the body in the shape of complex compounds containing comparatively little oxygen; as constantly, the elements of the food (whether before or after they have formed part of the living substance) are leaving the body, combined with more oxygen. And the incessant breaking down and oxidation of the complex compounds which enter the body are definitely proportioned to the amount of energy the body gives out, whether in the shape of heat or otherwise; just in the same way as the amount of work to be got out of a steam-engine, and the amount of heat it and its furnace give off, bear a strict proportion to its consumption of fuel.

8. From these general considerations regarding the nature of life, considered as physiological work, we may turn for the purpose of taking a like broad survey of the apparatus which does the work. We have seen the general performance of the engine, we may now look at its build.

The human body is obviously separable into *head*, *trunk*, and *limbs*. In the head, the brain-case or *skull* is distinguishable from the *face*. The trunk is naturally divided into the chest or *thorax*, and the belly or *abdomen*. Of the limbs there are two pairs—the upper, or *arms*, and the lower, or *legs*; and legs and arms again are subdivided by their joints into parts which obviously exhibit a rough correspondence—*thigh* and *upper arm*, *leg* and *fore-arm*, *ankle* and *wrist*, *fingers* and *toes*, plainly answering to one another. And the two last, in fact, are so similar that they receive the same name of *digits*; while the several joints of the fingers and toes have the common denomination of *phalanges*.

The whole body thus composed (without the viscera) is seen to be bilaterally symmetrical; that is to say, if it were split lengthways by a great knife, which should be made to pass along the middle line of both the dorsal and

ventral (or back and front) aspects, the two halves would almost exactly resemble one another.

9. One-half of the body, divided in the manner described (Fig. 1, A), would exhibit in the trunk, the cut faces of thirty-three bones, joined together by a very strong and tough substance into a long column, which lies much nearer the *dorsal* (or back) than the *ventral* (or front) aspect of the body. The bones thus cut through are called the *bodies* of the *vertebræ*. They separate a long, narrow canal, called the *spinal canal*, which is placed upon their dorsal side, from the spacious chamber of the chest and abdomen, which lies upon their ventral side. There is no direct communication between the dorsal canal and the ventral cavity.

The spinal canal contains a long white cord—the *spinal cord*—which is an important part of the nervous system. The ventral chamber is divided into the two subordinate cavities of the thorax and abdomen by a remarkable, partly fleshy and partly membranous, partition, the *diaphragm* (Fig. 1, *D*), which is concave towards the abdomen, and convex towards the thorax. The *alimentary canal* (Fig. 1, *Al.*) traverses these cavities from one end to the other, piercing the diaphragm. So does a long double series of distinct masses of nervous substance, which are called *ganglia*, are connected together by nervous cords, and constitute the so-called *sympathetic* (Fig. 1, *Sy.*). The abdomen contains, in addition to these parts, the two *kidneys*, one placed against each side of the vertebral column, the *liver*, the *pancreas* or "sweetbread" and the *spleen*. The thorax incloses, besides its segment of the alimentary canal and of the sympathetic, the *heart* and the two *lungs*. The latter are placed one on each side of the heart, which lies nearly in the middle of the thorax.

Where the body is succeeded by the head, the uppermost of the thirty-three vertebral bodies is followed by a continuous mass of bone, which extends through the whole length of the head, and, like the spinal column, separates a dorsal chamber from a ventral one. The dorsal chamber, or *cavity of the skull*, opens into the spinal canal. It contains a mass of nervous matter called the *brain*, which is continuous with the spinal cord, the brain and the spinal cord together constituting what is termed the *cerebro-spinal*

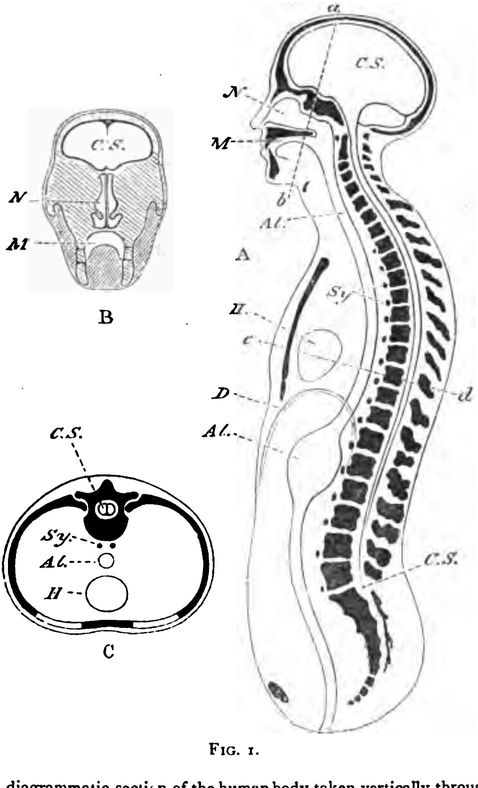

FIG. 1.

A. A diagrammatic section of the human body taken vertically through the median plane. *C.S.* the cerebro-spinal nervous system; *N*, the cavity of the nose; *M*, that of the mouth; *Al. Al.* the alimentary canal represented as a simple straight tube; *H*, the heart; *D*, the diaphragm; *Sy*, the sympathetic ganglia.

B. A transverse vertical section of the head taken along the line *a b*; letters as before.

C. A transverse section taken along the line *c d*; letters as before.

axis (Fig. *C.S.*, *C.S.*). The ventral chamber, or *cavity of the face*, is almost entirely occupied by the *mouth* and *pharynx*, into which last the upper end of the alimentary canal (called gullet or *œsophagus*) opens.

10. Thus, the study of a longitudinal section shows us that the human body is a double tube, the two tubes being completely separated by the spinal column and the bony axis of the skull, which form the floor of the one tube and the roof of the other. The dorsal tube contains the cerebro-spinal axis; the ventral tube contains the alimentary canal, the sympathetic nervous system, the heart, and the lungs, besides other organs.

Transverse sections, taken perpendicularly to the axis of the vertebral column, or to that of the skull, show still more clearly that this is the fundamental structure of the human body, and that the great apparent difference between the head and the trunk is due to the different size of the dorsal cavity relatively to the ventral. In the head the former cavity is very large in proportion to the size of the latter (Fig. 1, B); in the thorax, or abdomen it is very small (Fig. 1, C).

The limbs contain no such chambers as are found in the body and the head; but with the exception of certain branching tubes filled with fluid, which are called *blood-vessels* and *lymphatics*, are solid or semi-solid, throughout.

11. Such being the general character and arrangement of the parts of the human body, it will next be well to consider into what constituents it may be separated by the aid of no better means of discrimination than the eye and the anatomist's knife.

With no more elaborate aids than these, it becomes easy to separate that tough membrane which invests the whole body, and is called the skin, or *integument*, from the parts which lie beneath it. Furthermore, it is readily enough ascertained that this integument consists of two portions: a superficial layer, which is constantly being shed in the form of powder or scales composed of minute particles of horny matter, and is called the *epidermis*; and the deeper part, the *dermis*, which is dense and fibrous (Fig. 32). The epidermis, if wounded, neither gives rise to pain nor bleeds. The dermis, under like circumstances, is very tender, and bleeds freely. A practical

distinction is drawn between the two in shaving, in the course of which operation the razor ought to cut only epidermic structures; for if it go a shade deeper, it gives rise to pain and bleeding.

The skin can be readily enough removed from all parts of the exterior, but at the margins of the apertures of the body it seems to stop, and to be replaced by a layer which is much redder, more sensitive, bleeds more readily, and which keeps itself continually moist by giving out a more or less tenacious fluid, called *mucus*. Hence, at these apertures, the skin is said to stop, and to be replaced by *mucous membrane*, which lines all those interior cavities, such as the alimentary canal, into which the apertures open. But, in truth, the skin does not really come to an end at these points, but is directly continued into the mucous membrane, which last is simply an integument of greater delicacy, but consisting fundamentally of the same two layers,—a deep, fibrous layer, containing blood-vessels, and a superficial bloodless one, now called the *epithelium*. Thus every part of the body might be said to be contained between the walls of a double bag, formed by the epidermis, which invests the outside of the body, and the epithelium, its continuation, which lines the alimentary canal and similar cavities.

12. The dermis, and the deep, sanguine layer, which answers to it in the mucous membranes, are chiefly made up of a filamentous substance, which yields abundant *gelatine* on being boiled, and is the matter which tans when hide is made into leather. This is called *areolar*, *fibrous*, or, better, *connective* tissue.[1] The last name is the best, because this tissue is the great connecting medium by which the different parts of the body are held together. Thus it passes from the dermis between all the other organs, ensheathing the muscles, coating the bones and cartilages, and eventually reaching and entering into the mucous membranes. And so completely and thoroughly does the connective tissue permeate almost all parts of the body, that if every other tissue could be dissected away, a complete model of all the organs would be left composed of this tissue. Connective tissue varies very

[1] Every such constituent of the body, as epidermis, cartilage, or muscle, is called a "tissue." (See Lesson XII.)

much in character; in some places being very soft and tender, at others—as in the tendons and ligaments, which are almost wholly composed of it—attaining great strength and density.

13. Among the most important of the tissues imbedded in and ensheathed by the connective tissue, are some the presence and action of which can be readily determined during life.

If the upper arm of a man whose arm is stretched out be tightly grasped by another person, the latter, as the former bends up his fore-arm, will feel a great soft mass which lies at the fore part of the upper arm, swell, harden, and become prominent. As the arm is extended again, the swelling and hardness vanish.

On removing the skin, the body which thus changes its configuration is found to be a mass of red flesh, sheathed in connective tissue. The sheath is continued at each end into a tendon, by which the muscle is attached, on the one hand, to the shoulder-bone, and, on the other, to one of the bones of the fore-arm. This mass of flesh is the *muscle* called *biceps*, and it has the peculiar property of changing its dimensions—shortening and becoming thick in proportion to its decrease in length—when influenced by the will as well as by some other causes,[1] and of returning to its original form when let alone. This temporary change in the dimensions of a muscle, this shortening and becoming thick, is spoken of as its *contraction*. It is by reason of this property that muscular tissue becomes the great motor agent of the body; the muscles being so disposed between the systems of levers which support the body, that their contraction necessitates the motion of one lever upon another.

14. These levers form part of the system of hard tissues which constitute the *skeleton*. The less hard of these are the *cartilages*, composed of a dense, firm substance, ordinarily known as "gristle." The harder are the *bones*, which are masses of tissue allied to cartilage, or to connective tissue, hardened by being impregnated with *phosphate* and *carbonate of lime*. They are animal tissues which have become, in a manner, naturally petrified; and when the salts of lime are extracted, as they may be, by

[1] Such causes are called *stimuli*.

the action of acids, a model of the bone in soft and flexible animal matter remains.

More than 200 separate bones are ordinarily reckoned in the human body, though the actual number of distinct bones varies at different periods of life, many bones which are separate in youth becoming united together in old age. Thus there are originally, as we have seen, thirty-three separate bodies of vertebræ in the spinal column, and the upper twenty-four of these commonly remain distinct throughout life. But the twenty-fifth, twenty-sixth, twenty-seventh, twenty-eighth, and twenty-ninth early unite into one great bone, called the *sacrum;* and the four remaining vertebræ often run into one bony mass called the *coccyx*. In early adult life, the skull contains twenty-two naturally separate bones, but in youth the number is much greater, and in old age far less. Twenty-four ribs bound the chest laterally, twelve on each side, and most of them are connected by cartilages with the breast-bone. In the girdle which supports the shoulder, two bones are always distinguishable as the *scapula* and the *clavicle*. The *pelvis*, to which the legs are attached, consists of two separate bones called the *ossa innominata* in the adult; but each *os innominatum* is separable into three (called *pubis*, *ischium*, and *ilium*) in the young. There are thirty bones in each of the arms, and the same number in each of the legs, counting the *patella*, or knee pan.

All these bones are fastened together by ligaments, or by cartilages; and where they play freely over one another, a coat of cartilage furnishes the surfaces which come into contact. The cartilages which thus form part of a joint are called *articular* cartilages, and their free surfaces, by which they rub against each other, are lined by a delicate *synovial* membrane, which secretes a lubricating fluid—the *synovia*.

15. Though the bones of the skeleton are all strongly enough connected together by ligaments and cartilages, the joints play so freely, and the centre of gravity of the body, when erect, is so high up, that it is impossible to make a skeleton or a dead body support itself in the upright position. That position, easy as it seems, is the result of the contraction of a multitude of muscles which oppose and balance one another. Thus, the foot affording

the surface of support, the muscles of the calf (Fig. 2, I) must contract, or the legs and body would fall forward.

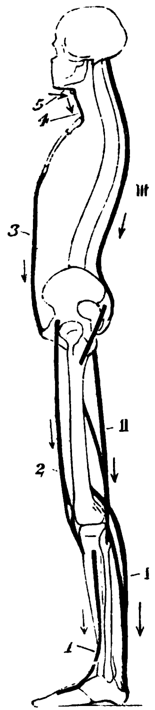

FIG. 2.—A DIAGRAM ILLUSTRATING THE ATTACHMENTS OF SOME OF THE MOST IMPORTANT MUSCLES WHICH KEEP THE BODY IN THE ERECT POSTURE.

I. The muscles of the calf. II. Those of the back of the thigh. III. Those of the spine. These tend to keep the body from falling forward.
1. The muscles of the front of the leg. 2. Those of the front of the thigh. 3. Those of the front of the abdomen. 4, 5. Those of the front of the neck. These tend to keep the body from falling backwards. The arrows indicate the direction of action of the muscles, the foot being fixed.

But this action tends to bend the leg; and to neutralize this and keep the leg straight, the great muscles in front of the thigh (Fig. 2, 2) must come into play. But these, by the same action, tend to bend the body forward on the legs; and if the body is to be kept straight, they must be neutralized by the action of the muscles of the buttocks and of the back (Fig. 2, III).

The erect position, then, which we assume so easily and without thinking about it, is the result of the combined and accurately proportioned action of a vast number of muscles. What is it that makes them work together in this way?

16. Let any person in the erect position receive a violent blow on the head, and you know what occurs. On the instant he drops prostrate, in a heap, with his limbs relaxed and powerless. What has happened to him? The blow may have been so inflicted as not to touch a single muscle of the body; it may not cause the loss of a drop of blood: and, indeed, if the "concussion," as it is called, has not been too severe, the sufferer, after a few moments of unconsciousness, will come to himself, and be as well as ever again. Clearly, therefore, no permanent injury has been done to any part of the body, least of all to the muscles, but an influence has been exerted upon a something which governs the muscles. And a similar influence may be the effect of very subtle causes. A strong mental emotion, and even a very bad smell, will, in some people, produce the same effect as a blow.

These observations might lead to the conclusion that it is the mind which directly governs the muscles, but a little further inquiry will show that such is not the case. For people have been so stabbed, or shot in the back, as to cut the spinal cord, without any considerable injury to other parts: and then they have lost the power of standing upright as much as before, though their minds may have remained perfectly clear. And not only have they lost the power of standing upright under these circumstances, but they no longer retain any power of either feeling what is going on in their legs, or, by an act of their volition, causing motion in them.

17. And yet, though the mind is thus cut off from the

lower limbs, a controlling and governing power over them still remains in the body. For if the soles of the disabled feet be tickled, though the mind does not feel the tickling, the legs will be jerked up, just as would be the case in an uninjured person. Again, if a series of galvanic shocks be sent along the spinal cord, the legs will perform movements even more powerful than those which the will could produce in an uninjured person. And, finally, if the injury is of such a nature as not simply to divide or injure the spinal cord in one place only, but to crush or profoundly disorganise it altogether, all these phenomena cease; tickling the soles, or sending galvanic shocks along the spine, will produce no effect upon the legs.

By examinations of this kind carried still further, we arrive at the remarkable result that while the brain is the seat of all sensation and mental action, and the primary source of all voluntary muscular contractions, the spinal cord is by itself capable of receiving an impression from the exterior, and converting it not only into a simple muscular contraction, but into a combination of such actions.

Thus, in general terms, we may say of the cerebro-spinal nervous centres, that they have the power, when they receive certain impressions from without, of giving rise to simple or combined muscular contractions.

18. But you will further note that these impressions from without are of very different characters. Any part of the surface of the body may be so affected as to give rise to the sensations of contact, or of heat or cold; and any or every substance is able, under certain circumstances, to produce these sensations. But only very few and comparatively small portions of the bodily framework are competent to be affected, in such a manner as to cause the sensations of taste or of smell, of sight or of hearing: and only a few substances, or particular kinds of vibrations, are able so to affect those regions. These very limited parts of the body, which put us in relation with particular kinds of substances, or forms of force, are what are termed *sensory organs*. There are two such organs for sight, two for hearing, two for smell, and one, or more strictly speaking two, for taste.

19. And now that we have taken this brief view of the

structure of the body, of the organs which support it, of the organs which move it, and of the organs which put it in relation with the surrounding world, or, in other words, enable it to move in harmony with influences from without, we must consider the means by which all this wonderful apparatus is kept in working order.

All work, as we have seen, implies waste. The work of the nervous system and that of the muscles, therefore, implies consumption either of their own substance, or of something else. And as the organism can make nothing, it must possess the means of obtaining from without that which it wants, and of throwing off from itself that which it wastes; and we have seen that, in the gross, it does these things. The body feeds, and it excretes. But we must now pass from the broad fact to the mechanism by which the fact is brought about. The organs which convert food into nutriment are the organs of *alimentation;* those which distribute nutriment all over the body are organs of *circulation;* those which get rid of the waste products are organs of *excretion.*

20. The organs of alimentation are the mouth, pharynx, gullet, stomach, and intestines, with their appendages. What they do is, first to receive and grind the food. They then act upon it with chemical agents, of which they possess a store which is renewed as fast as it is wasted; and in this way separate the food into a fluid containing nutritious matters in solution or suspension, and innutritious dregs or *fæces.*

21. A system of minute tubes, with very thin walls, termed *capillaries*, is distributed through the whole organism except the epidermis and its products, the epithelium, the cartilages, and the substance of the teeth. On all sides, these tubes pass into others, which are called *arteries* and *veins;* while these, becoming larger and larger, at length open into the *heart*, an organ which, as we have seen, is placed in the thorax. During life, these tubes and the chambers of the heart, with which they are connected, are all full of liquid, which is, for the most part, that red fluid with which we are all familiar as *blood.*

The walls of the heart are muscular, and contract rhythmically, or at regular intervals. By means of these

contractions the blood which its cavities contain is driven in jets out of these cavities, into the arteries, and thence into the capillaries, whence it returns by the veins back into the heart.

This is the *circulation of the blood.*

22. Now the fluid containing the dissolved or suspended nutritive matters which are the result of the process of digestion, traverses the very thin layer of soft and permeable tissue which separates the cavity of the alimentary canal from the cavities of the innumerable capillary vessels which lie in the walls of that canal, and so enters the blood, with which those capillaries are filled. Whirled away by the torrent of the circulation, the blood, thus charged with nutritive matter, enters the heart, and is thence propelled into the organs of the body. To these organs it supplies the nutriment with which it is charged; from them it takes their waste products, and, finally, returns by the veins, loaded with useless and injurious excretions, which sooner or later take the form of water, carbonic acid, and urea.

23. These excretionary matters are separated from the blood by the *excretory organs*, of which there are three—the *skin*, the *lungs*, and the *kidneys.*

Different as these organs may be in appearance, they are constructed upon one and the same principle. Each, in ultimate analysis, consists of a very thin sheet of tissue, like so much delicate blotting-paper, the one face of which is free, or lines a cavity in communication with the exterior of the body, while the other is in contact with the blood which has to be purified.

The excreted matters are, as it were (though, as we shall see, in a peculiar way), strained from the blood, through this delicate layer of filtering-tissue, and on to its free surface, whence they make their escape.

Each of these organs is especially concerned in the elimination of one of the chief waste products—water, carbonic acid, and urea—though it may at the same time be a means of escape for the others. Thus the lungs are especially busied in getting rid of carbonic acid, but at the same time they give off a good deal of water. The duty of the kidneys is to excrete urea (together with other saline matters), but at the same time they pass away a

large quantity of water and a trifling amount of carbonic acid; while the skin gives off much water, some amount of carbonic acid, and a certain quantity of saline matter, among which urea may be, sometimes at all events, present.

24. Finally the lungs play a double part, being not merely eliminators of waste, or excretionary products, but importers into the economy of a substance which is not exactly either food or drink, but something as important as either,—to wit, *oxygen.*

As the carbonic acid (and water) is passing from the blood through the lungs into the external air, oxygen is passing from the air through the lungs into the blood, and is carried, as we shall see, by the blood to all parts of the body. We have seen (p. 5) that the waste which leaves the body contains more oxygen than the food which enters the body. Indeed oxidation, the oxygen being supplied by the blood, is going on all over the body. All parts of the body are continually being oxidized, or, in other words, are continually *burning*, some more rapidly and fiercely than others. And this burning, though it is carried on in a peculiar manner, so as never to give rise to a flame, yet nevertheless produces an amount of heat which is as efficient as a fire to raise the blood to a temperature of about 100°; and this hot fluid, incessantly renewed in all parts of the economy by the torrent of the circulation, warms the body, as a house is warmed by a hot-water apparatus. Nor is it alone the heat of the body which is provided by this oxidation; the energy which appears in the muscular work done by the body has the same source. Just as the burning of the coal in a steam-engine supplies the motive power which drives the wheels, so, though in a peculiar way, the oxidation of the muscles (and thus ultimately of the food) supplies the motive power of those muscular contractions which carry out the movements of the body. The food, like coal combustible or capable of oxidation, is built up into the living body, which in like manner combustible, is continually being oxidized by the oxygen of the blood, thus doing work and giving out heat. Some of the food perhaps may be oxidized without ever actually forming part of the body or after it has already become waste matter, but this does not concern us now.

25. These alimentary, distributive or circulatory, excretory, and combustive processes would however be worse than useless if they were not kept in strict proportion one to another. If the state of physiological balance is to be maintained, not only must the quantity of aliment taken be at least equivalent to the quantity of matter excreted; but that aliment must be distributed with due rapidity to the seat of each local waste. The circulatory system is the commissariat of the physiological army.

Again, if the body is to be maintained at a tolerably even temperature, while that of the air is constantly varying, the condition of the hot-water apparatus must be most carefully regulated.

In other words, a *combining organ* must be added to the organs already mentioned, and this is found in the nervous system, which not only possesses the function already described of enabling us to move our bodies and to know what is going on in the external world; but makes us aware of the need of food, enables us to discriminate nutritious from innutritious matters, and to exert the muscular actions needful for seizing, killing, and cooking; guides the hand to the mouth, and governs all the movements of the jaws and of the alimentary canal. By it, the working of the heart is properly adjusted and the calibres of the distributing pipes are regulated, so as indirectly to govern the excretory and combustive processes. And these are also more directly affected by other actions of the nervous system.

26. The various functions which have been thus briefly indicated constitute the greater part of what are called the *vital actions* of the human body, and so long as they are performed, the body is said to possess *life*. The cessation of the performance of these functions is what is ordinarily called *death*.

But there are really several kinds of death, which may, in the first place, be distinguished from one another under the two heads of *local* and of *general* death.

27. *Local death* is going on at every moment, and in most, if not in all, parts of the living body. Individual cells of the epidermis and of the epithelium are incessantly dying and being cast off, to be replaced by others which are, as constantly, coming into separate existence.

The like is true of blood-corpuscles, and probably of many other elements of the tissues.

This form of local death is insensible to ourselves, and is essential to the due maintenance of life. But, occasionally, local death occurs on a larger scale, as the result of injury, or as the consequence of disease. A burn, for example, may suddenly kill more or less of the skin; or part of the tissues of the skin may die, as in the case of the slough which lies in the midst of a boil; or a whole limb may die, and exhibit the strange phenomena of *mortification.*

The local death of some tissues is followed by their regeneration. Not only all the forms of epidermis and epithelium, but nerves, connective tissue, bone, and at any rate, some muscles, may be thus reproduced, even on a large scale.

28. *General death* is of two kinds, *death of the body as a whole*, and *death of the tissues.* By the former term is implied the absolute cessation of the functions of the brain, of the circulatory, and of the respiratory organs; by the latter, the entire disappearance of the vital actions of the ultimate structural constituents of the body. When death takes place, the body, as a whole, dies first, the death of the tissues not occurring until after an interval, which is sometimes considerable.

Hence it is that, for some little time after what is ordinarily called death, the muscles of an executed criminal may be made to contract by the application of proper stimuli. The muscles are not dead, though the man is.

29. The modes in which death is brought about appear at first sight to be extremely varied. We speak of natural death by old age, or by some of the endless forms of disease; of violent death by starvation, or by the innumerable varieties of injury, or poison. But, in reality, the immediate cause of death is always the stoppage of the functions of one of three organs; the cerebro-spinal nervous centre, the lungs, or the heart. Thus, a man may be instantly killed by such an injury to a part of the brain which is called the *medulla oblongata* (see Lesson XI.) as may be produced by hanging, or breaking the neck.

Or death may be the immediate result of suffocation

by strangulation, smothering, or drowning,—or, in other words, of stoppage of the respiratory functions.

Or, finally, death ensues at once when the heart ceases to propel blood. These three organs—the brain, the lungs, and the heart—have been fancifully termed the *tripod of life.*

In ultimate analysis, however, life has but two legs to stand upon, the lungs and the heart, for death through the brain is always the effect of the secondary action of the injury to that organ upon the lungs or the heart. The functions of the brain cease, when either respiration or circulation is at an end. But if circulation and respiration are kept up artificially, the brain may be removed without causing death. On the other hand, if the blood be not aërated, its circulation by the heart cannot preserve life; and, if the circulation be at an end, mere aëration of the blood in the lungs is equally ineffectual for the prevention of death.

30. With the cessation of life, the everyday forces of the inorganic world no longer remain the servants of the bodily frame, as they were during life, but become its masters. Oxygen, the slave of the living organism, becomes the lord of the dead body. Atom by atom, the complex molecules of the tissues are taken to pieces and reduced to simpler and more oxidized substances, until the soft parts are dissipated chiefly in the form of carbonic acid, ammonia, water, and soluble salts, and the bones and teeth alone remain. But not even these dense and earthy structures are competent to offer a permanent resistance to water and air. Sooner or later the animal basis which holds together the earthy salts decomposes and dissolves—the solid structures become friable, and break down into powder. Finally, they dissolve and are diffused among the waters of the surface of the globe, just as the gaseous products of decomposition are dissipated through its atmosphere.

It is impossible to follow, with any degree of certainty, wanderings more varied and more extensive than those imagined by the ancient sages who held the doctrine of transmigration; but the chances are, that sooner or later, some, if not all, of the scattered atoms will be gathered into new forms of life.

The sun's rays, acting through the vegetable world, build up some of the wandering molecules of carbonic acid, of water, of ammonia, and of salts, into the fabric of plants. The plants are devoured by animals, animals devour one another, man devours both plants and other animals; and hence it is very possible that atoms which once formed an integral part of the busy brain of Julius Cæsar may now enter into the composition of Cæsar the negro in Alabama, and of Cæsar the house-dog in an English homestead.

And thus there is sober truth in the words which Shakespeare puts into the mouth of Hamlet—

> "Imperial Cæsar, dead and turned to clay,
> Might stop a hole to keep the cold away;
> Oh that that earth, which kept the world in awe,
> Should patch a wall, t' expel the winter's flaw!"

LESSON II.

THE VASCULAR SYSTEM AND THE CIRCULATION.

1. ALMOST all parts of the body are *vascular;* that is to say, they are traversed by minute and very close-set canals, which open into one another so as to constitute a small-meshed network, and confer upon these parts a spongy texture. The canals, or rather tubes, are provided with distinct but very delicate walls, composed of what at first sight appears to be a structureless membrane (Fig. 3 A, *a*), but is in reality formed of a number of thin scales, called "cells," cemented together at their edges; in each of these cells lies a small oval body (Fig. 3 A, *b*), termed a *nucleus* (see Lesson XII. § 2).

These tubes are the *capillaries.* They vary in diameter from $\frac{1}{2000}$th to $\frac{1}{1500}$th of an inch; they are sometimes disposed in loops, sometimes in long, sometimes in wide, sometimes in narrow meshes; and the diameters of these meshes, or, in other words, the interspaces between the capillaries, are sometimes hardly wider than the diameter of a capillary, sometimes many times as wide (see Figs. 16, 20, 32, 33, and 37). These interspaces are occupied by the substance of the tissue which the capillaries permeate (Fig. 3 A, *c*) so that the ultimate anatomical components of every part of the body are, strictly speaking, outside the vessels, or *extra-vascular.*

But there are certain parts which, in another and broader sense, are also said to be extra-vascular or non-vascular. These are the epidermis and epithelium, the nails and hairs, the substance of the teeth, and to a certain extent the cartilages; which may and do attain a very considerable thickness or length, and yet contain no

vessels. However, since we have seen that all the tissues are really extra-vascular, these differ only in degree from the rest. The circumstance that all the tissues are outside the vessels by no means interferes with their being bathed by the fluid which is inside the vessels. In fact, the walls of the capillaries are so exceedingly thin that their fluid

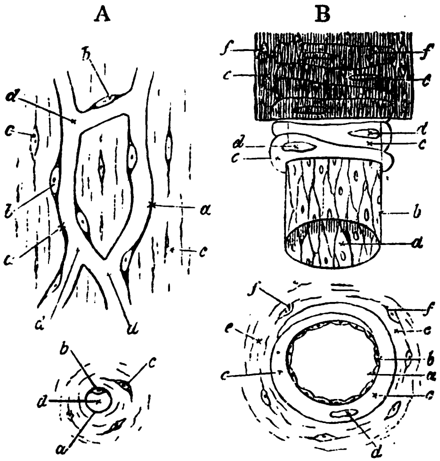

FIG. 3.

A. Diagrammatic representation of a capillary seen from above and in section: *a*, the wall of the capillary with *b*, the nuclei; *c*, nuclei belonging to the connective tissue in which the capillary is supposed to be lying; *d*, the canal of the capillary.

B. Diagrammatic representation of the structure of a small artery: *a*, epithelium; *b*, the so-called basement membrane; *c*, the circular non-striated muscular fibres, each with nucleus *d*; *e*, the coat of fibrous tissue with nuclei *f*.

contents readily exude through the delicate membrane of which they are composed, and irrigate the tissues in which they lie.

2. The capillary tubes thus described contain, during life, the red fluid, *blood*. There are other somewhat

similar tubes, also sometimes called capillaries, but these are filled with a pale, watery, or milky fluid, termed *lymph*, or *chyle*, and are called lymphatics. The capillaries, which contain blood, are continued on different sides, into somewhat larger tubes, with thicker walls, which are the smallest *arteries* and *veins*, and these again join on to larger arteries and veins.

The mere fact that the walls of these vessels are thicker than those of the capillaries constitutes an important difference between the capillaries and the small arteries and veins; for the walls of the latter are thus rendered far less permeable to fluids, and that thorough irrigation of the tissues, which is effected by the capillaries, cannot be performed by them.

The most important difference between these vessels and the capillaries, however, lies in the circumstance that their walls are not only thicker, but also more complex, being composed of several coats, one, at least, of which is muscular. The number, arrangement, and even nature of these coats differ according to the size of the vessels, and are not the same in the veins as in the arteries, though the smallest veins and arteries tend to resemble each other.

If we take one of the smallest arteries, we find, first, a very delicate lining of cells constituting a sort of epithelium continuous with the cells which form the only coat of the capillaries (Fig. 3 B, *a*). Outside this, separated from it by a thin but strong membrane (shown as a mere line at Fig. 3 B, *b*), comes the muscular coat of the kind called *plain* or *non-striated* muscle (see Lesson XII.), made up of flattened spindle-shape fibres which are wrapped round the vessel (Fig. 3 B, *c*).

Outside the muscular coat is a sheath of fibrous or connective tissue (Fig. 3 B, *f*).

In the smallest arteries there is but a single layer of these muscular fibres encircling the vessel like a series of rings; but in the larger arteries there are several layers of circular muscular fibres variously bound together with fibrous and elastic tissue, though as the vessels get larger the quantity of muscular tissue in them gets *relatively* less.

Now these plain muscular fibres possess that same

power of contraction, or shortening in the long, and broadening in the narrow, directions, which, as was stated in the preceding Lesson, is the special property of muscular tissue. And when they exercise this power, they, of course, narrow the calibre of the vessel, just as squeezing it with the hand or in any other way would do; and this contraction may go so far as, in some cases, to reduce the cavity of the vessel almost to nothing, and to render it practically impervious.

The state of contraction of these muscles of the small arteries is regulated, like that of other muscles, by their nerves; or, in other words, the nerves supplied to the vessels determine whether the passage through these tubes should be wide and free, or narrow and obstructed. Thus while the small arteries lose the function, which the capillaries possess, of directly irrigating the tissues by transudation, they gain that of regulating the supply of fluid to the irrigators or capillaries themselves. The contraction, or dilatation, of the arteries which supply a set of capillaries, comes to the same result as lowering or raising the sluice-gates of a system of irrigation-canals.

3. The smaller arteries and veins severally unite into, or are branches of, larger arterial or venous trunks, which again spring from or unite into still larger ones, and these, at length, communicate by a few principal arterial and venous trunks with the heart.

The smallest arteries and veins, as we have seen, are similar in structure, but the larger arteries and veins differ widely; for the larger arteries have walls so thick and stout that they do not sink together when empty; and this thickness and stoutness arises from the circumstance that not only is the muscular coat very thick, but that in addition, and more especially, several layers of a highly elastic, strong, fibrous substance become mixed up with the muscular layers. Thus, when a large artery is pulled out and let go, it stretches and returns to its primitive dimensions almost like a piece of india-rubber.

The larger veins, on the other hand, contain but little of either elastic or muscular tissue. Hence, their walls are thin, and they collapse when empty.

This is one great difference between the larger arteries

and the veins; the other is the presence of what are termed *valves* in a great many of the veins, especially in those which lie in muscular parts of the body. They are absent in the largest trunks, and in the smallest branches, and in all the divisions of the portal, pulmonary, and cerebral veins.

4. These valves are pouch-like folds of the inner wall of the vein. The bottom of the pouch is turned towards those capillaries from which the vein springs. The free edge of the pouch is directed the other way, or towards the heart. The action of these pouches is to impede the passage of any fluid from the heart towards the capillaries, while they do not interfere with fluid passing in the opposite direction (Fig. 4). The working of some of these valves may be very easily demonstrated in the living body.

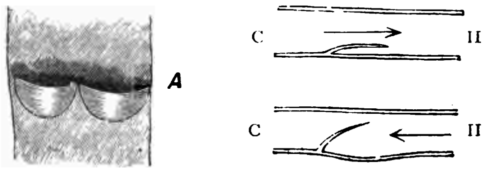

FIG. 4.—THE VALVES OF VEINS.

C, H, C, H, Diagrammatic sections of veins with valves. In the upper figure the blood is supposed to be flowing in the direction of the arrow, towards the heart; in the lower, back towards the capillaries; C, capillary side; H, heart side. A, a vein laid open to show a pair of pouch shaped valves.

When the arm is bared, blue veins may be seen running from the hand, under the skin, to the upper arm. The diameter of these veins is pretty even, and diminishes regularly towards the hand, so long as the current of the blood, which is running in them, from the hand to the upper arm, is uninterrupted.

But if a finger be pressed upon the upper part of one of these veins, and then passed downwards along it, so as to drive the blood which it contains backwards, sundry swellings, like little knots, will suddenly make their appearance at several points in the length of the vein, where nothing of the kind was visible before. These swellings are simply dilatations of the wall of the vein, caused by the pressure of the blood on that wall, above a valve

which opposes its backward progress. The moment the backward impulse ceases the blood flows on again ; the valve, swinging back towards the wall of the vein, affords no obstacle to its progress, and the distension caused by its pressure disappears (Fig. 4).

The only arteries which possess valves are the primary trunks—the aorta and pulmonary artery—which spring from the heart, and these valves, since they really belong to the heart, will be best considered with that organ.

5. Besides the capillary network and the trunks connected with it, which constitute the blood-vascular system, all parts of the body which possess blood capillaries also contain another set of what are termed *lymphatic* capillaries, mixed up with those of the blood-vascular system, but not directly communicating with them, and, in addition, differing from the blood capillaries in being connected with larger vessels of only one kind. That is to say, they open only into trunks which carry fluid away from them, there being no large vessels which bring anything to them.

FIG. 5.—THE LYMPHATICS OF THE FRONT OF THE RIGHT ARM.

g. Lymphatic glands, or *ganglia* as they are sometimes called. These *ganglia* are not to be confounded with nervous *ganglia*.

These trunks further resemble the small veins in being abundantly provided with valves which freely allow of the passage of liquid from the lymphatic capillaries, but obstruct the flow of anything the other way. But the lymphatic trunks differ from the veins, in that they do not rapidly unite into larger and larger trunks, which present a continually increasing calibre, and allow of a flow without interruption to the heart. On the contrary, remaining nearly of the same size, they, at intervals, enter and ramify in rounded bodies called *lymphatic glands*, whence new lymphatic trunks

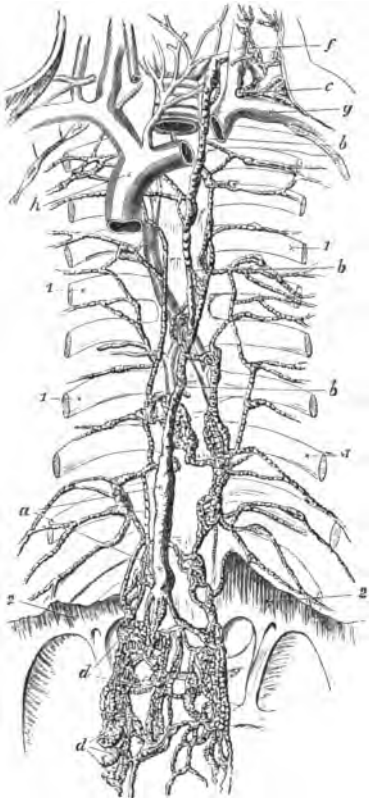

FIG. 6.—THE THORACIC DUCT.

The Thoracic Duct occupies the middle of the figure. It lies upon the spinal column, at the sides of which are seen portions of the ribs (1).

a, the receptacle of the chyle; *b*, the trunk of the thoracic duct, opening at *c* into the junction of the left jugular (*f*) and subclavian (*g*) veins as they unite into the left innominate vein, which has been cut across to show the thoracic duct running behind it; *d*, lymphatic glands placed in the lumbar regions; *h*, the superior vena cava formed by the junction of the right and left innominate veins.

arise (Fig. 5). In these glands the lymphatic capillaries and passages are closely interlaced with blood capillaries.

Sooner or later, however, the great majority of the smaller lymphatic trunks pour their contents into a tube, which is about as large as a crow-quill, lies in front of the backbone, and is called the *thoracic duct*. This opens at the root of the neck into the conjoined trunks of the great veins which bring back the blood from the left side of the head and the left arm (Fig. 6). The remaining lymphatics are connected by a common canal with the corresponding vein on the right side.

Where the principal trunks of the lymphatic system open into the veins, valves are placed, which allow of the passage of fluid in one direction only, viz. from the lymphatic to the vein. Thus the lymphatic vessels are, as it were, a part of the venous system, though, by reason of these valves, the fluid which is contained in the veins cannot get into the lymphatics. On the other hand, every facility is afforded for the passage into the veins of the fluid contained in the lymphatics. Indeed, in consequence of the numerous valves in the lymphatics, every pressure on their walls, not being able to send the fluid backward, must drive it more or less forward, towards the veins.

6. The lower part of the thoracic duct is dilated, and is termed the *receptacle*, or *cistern*, of the *chyle* (*a*, Fig 6). In fact, it receives the lymphatics of the intestines, which, though they differ in no essential respect from other lymphatics, are called *lacteals*, because, after a meal containing much fatty matter, they are filled with a milky fluid, which is termed the *chyle*. The lacteals, or lymphatics of the small intestine, not only form networks in its walls, but send blind prolongations into the little velvety processes termed *villi*, with which the mucous membrane of that intestine is beset (see Lesson VI.). The trunks which open into the network lie in the *mesentery* (or membrane which suspends the small intestine to the back wall of the abdomen), and the glands through which these trunks lead are hence termed the *mesenteric glands*.

7. It will now be desirable to take a general view of the arrangement of all these different vessels, and of their

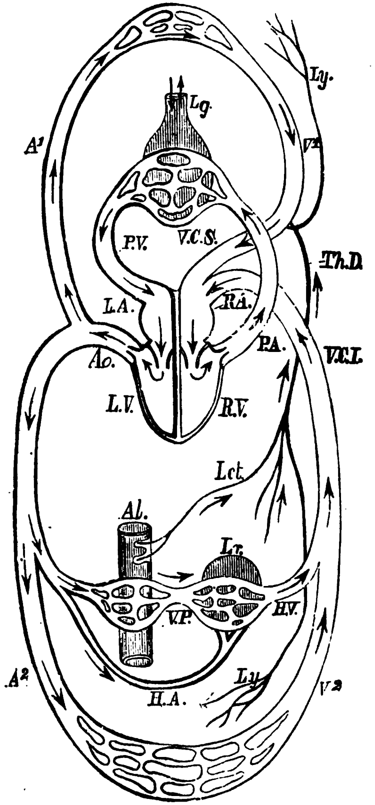

FIG. 7.—DIAGRAM OF THE HEART AND VESSELS, WITH THE COURSE OF THE CIRCULATION, VIEWED FROM BEHIND, SO THAT THE PROPER LEFT OF THE OBSERVER CORRESPONDS WITH THE LEFT SIDE OF THE HEART IN THE DIAGRAM.

L.A. left auricle; *L.V.* left ventricle; *Ao.* aorta; A^1. arteries to the upper part of the body; A^2. arteries to the lower part of the body; *H.A.* hepatic artery, which supplies the liver with part of its blood; V^1. veins of the upper

relations to the great central organ of the vascular system —the heart (Fig. 7).

All the veins of every part of the body, except the lungs, the heart itself, and certain viscera of the abdomen, join together into larger veins, which, sooner or later, open into one of two great trunks (Fig. 7, *V.C.S.* *V.C.I.*) termed the *superior* and the *inferior vena cava*, which debouch into the upper or broad end of the right half of the heart.

All the arteries of every part of the body, except the lungs, are more or less remote branches of one great trunk—the *aorta* (Fig. 7, *Ao.*), which springs from the lower division of the left half of the heart.

The arteries of the lungs are branches of a great trunk (Fig. 7, *P.A.*) springing from the lower division of the right side of the heart. The veins of the lungs, on the contrary, open by four trunks into the upper part of the left side of the heart (Fig. 7, *P.V.*).

Thus the venous trunks open into the upper division of each half of the heart: those of the body in general into that of the right half, those of the lungs into that of the left half; while the arterial trunks spring from the lower moieties of each half of the heart: that for the body in general from the left side, and that for the lungs from the right side.

Hence it follows that the great artery of the body, and the great veins of the body, are connected with opposite sides of the heart; and the great artery of the lungs and the great veins of the lungs also with opposite sides of that organ. On the other hand, the veins of the body open into the same side of the heart as the artery of the lungs, and the veins of the lungs open into the same side of the heart as the artery of the body.

The arteries which open into the capillaries of the substance of the heart are called *coronary arteries*, and arise,

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part of the body; *V*[2]. veins of the lower part of the body; *V.P.* vena portæ; *H.V.* hepatic vein; *V.C.I.* inferior vena cava; *V.C.S.* superior vena cava; *R.A.* right auricle; *R.V.* right ventricle: *P.A.* pulmonary artery; *Lg.* lung; *P.V.* pulmonary vein; *Lct.* lacteals; *Ly.* lymphatics; *Th.D.* thoracic duct; *Al.* alimentary canal; *Lr.* liver. The arrows indicate the course of the blood, lymph, and chyle. The vessels which contain arterial blood have dark contours, while those which carry venous blood have light contours.

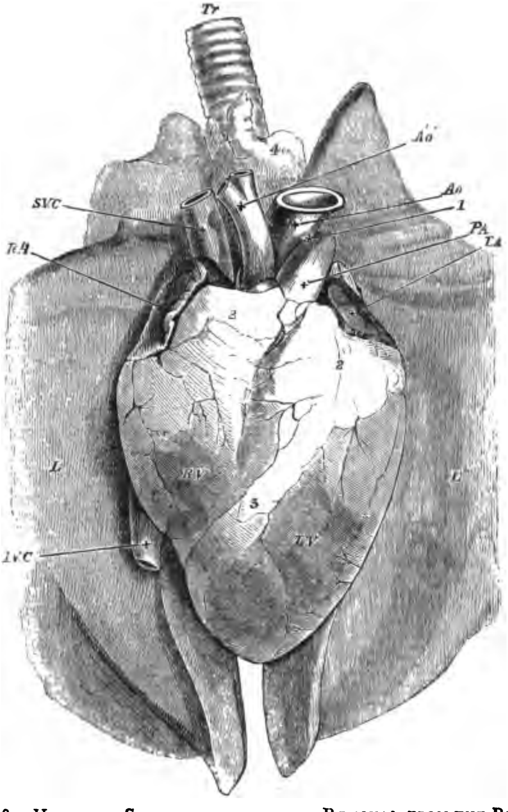

FIG. 8.—HEART OF SHEEP, AS SEEN AFTER REMOVAL FROM THE BODY, LYING UPON THE TWO LUNGS. THE PERICARDIUM HAS BEEN CUT AWAY, BUT NO OTHER DISSECTION MADE.

R.A. Auricular appendage of right auricle; *L.A.* auricular appendage of left auricle; *R.V.* right ventricle; *L.V.* left ventricle; *S.V.C.* superior vena cava; *I.V.C.* inferior vena cava; *P.A.* pulmonary artery; *Ao*, aorta; *A'o'*, innominate branch from aorta dividing into subclavian and carotid arteries;

like the other arteries, from the aorta, but quite close to its origin, just beyond the semilunar valves. But the *coronary vein*, which is formed by the union of the small veins which arise from the capillaries of the heart, does not open into either of the venæ cavæ, but pours the blood which it contains directly into the division of the heart into which these venæ cavæ open—that is to say, into the right upper division (Fig. 14 *b*).

The abdominal viscera referred to above, the veins of which do not take the usual course, are the stomach, the intestines, the spleen, and the pancreas. These veins all combine into a single trunk, which is termed the *vena portæ* (Fig. 7, *V.P.*), but this trunk does not open into the *vena cava inferior*. On the contrary, having reached the liver, it enters the substance of that organ, and breaks up into an immense multitude of capillaries, which ramify through the liver, and become connected with those into which the artery of the liver, called the *hepatic artery* (Fig. 7, *H.A.*), branches. From this common capillary mesh-work veins arise, and unite, at length, into a single trunk, the *hepatic vein* (Fig. 7, *H.V.*), which emerges from the liver, and opens into the *inferior vena cava*. The portal vein is the only great vein in the body which branches out and becomes continuous with the capillaries of an organ, like an artery.

8. The heart (Figs. 8 and 10), to which all the vessels in the body have now been directly or indirectly traced, is an organ, the size of which is usually roughly estimated as equal to that of the closed fist of the person to whom it belongs, and which has a broad end turned upwards and backwards, and rather to the right side, called its *base*: and a pointed end which is called its *apex*, turned downwards and forwards, and to the left side, so as to lie opposite the interval between the fifth and sixth ribs.

It is lodged between the lungs, nearer the front than the back wall of the chest, and is enclosed in a sort of double bag—the *pericardium* (Fig. 9, *p.*). One-half of the

L. lung; *Tr.* trachea. 1, solid cord often present, the remnant of a once open communication between the pulmonary artery and aorta. 2, masses of fat at the bases of the ventricle hiding from view the greater part of the auricles. 3, line of fat marking the division between the two ventricles. 4, mass of fat covering end of trachea.

double bag is closely adherent to the heart itself, forming a thin coat upon its outer surface. At the base of the heart, this half of the bag passes on to the great vessels which spring from, or open into, that organ; and becomes continuous with the other half, which loosely envelopes both the heart and the adherent half of the bag. Between the two layers of the pericardium, consequently, there is a completely closed, narrow cavity, lined by an epithelium, and secreting into its interior a small quantity of clear fluid.[1]

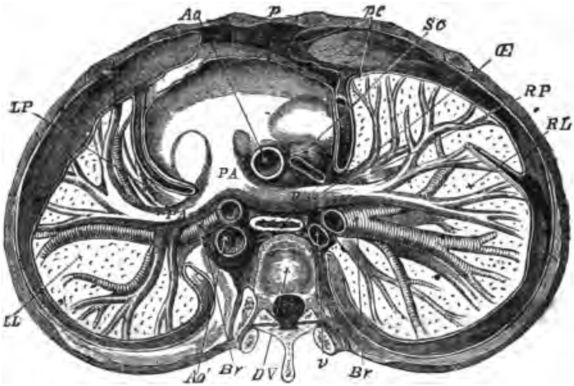

FIG. 9.—TRANSVERSE SECTION OF THE CHEST, WITH THE HEART AND LUNGS IN PLACE. (A little diagrammatic.)

D.V. dorsal vertebra, or joint of the backbone; *Ao. Ao'.* aorta, the top of its arch being cut away in this section; *S.C.* superior vena cava; *P.A.* pulmonary artery, divided into a branch for each lung; *L.P. R.P.* left and right pulmonary veins; *Br.* bronchi; *R.L. L.L.* right and left lungs; *Œ.* the gullet or œsophagus; *p.* outer bag of pericardium; *pl.* the two layers of pleura; *v.* azygos vein.

The outer layer of the pericardium is firmly connected below with the upper surface of the diaphragm.

But the heart cannot be said to depend altogether upon the diaphragm for support, inasmuch as the great vessels

[1] This fluid, like that contained in the peritoneum, pleura, and other shut sacs of a similar character to the pericardium, used to be called *serum*; whence the membranes forming the walls of these sacs are frequently termed *serous membranes*.

which issue from or enter it—and for the most part pass upwards from its base—help to suspend and keep it in place.

Thus the heart is coated, outside, by one layer of the pericardium. Inside, it contains two great cavities or "divisions," as they have been termed above, completely separated by a fixed partition which extends from the base to the apex of the heart; and consequently, having no

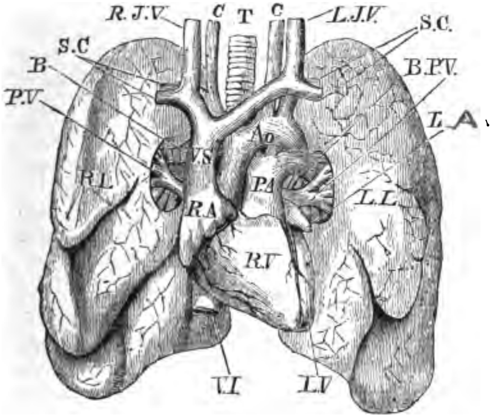

FIG. 10.—THE HEART, GREAT VESSELS, AND LUNGS. (FRONT VIEW.)

R.V. right ventricle; *L.V.* left ventricle; *R.A.* right auricle; *L.A.* left auricle; *Ao.* aorta; *P.A.* pulmonary artery; *P.V.* pulmonary veins; *R.L.* right lung; *L.L.* left lung; *V.S.* vena cava superior; *S.C.* subclavian vessels; *C.* carotids; *R.J.V.* and *L.J.V.* right and left jugular veins; *V.I.* vena cava inferior; *T.* trachea; *B.* bronchi.

All the great vessels but those of the lungs are cut.

direct communication with one another. Each of these two great cavities is further subdivided, not longitudinally but transversely, by a moveable partition. The cavity above the transverse partition on each side is called the *auricle;* the cavity below, the *ventricle*—right or left as the case may be.

Each of the four cavities has the same capacity, and is capable of containing from 4 to 6 cubic inches of water. The walls of the auricles are much thinner than those of the ventricles. The wall of the left ventricle is much thicker than that of the right ventricle; but no such difference is perceptible between the two auricles (Figs. 11 and 12, 1 and 3).

9. In fact, as we shall see, the ventricles have more work to do than the auricles, and the left ventricle more to do than the right. Hence the ventricles have more muscular substance than the auricles, and the left ventricle than the right; and it is this excess of muscular substance which gives rise to the excess of thickness observed in the left ventricle.

The muscular fibres of the heart are of a peculiar nature, resembling those of the chief muscles of the body in being transversely striped (see Lesson XII.), but differing from them in many other respects.

Almost the whole mass of the heart is made up of these muscular fibres, which have a very remarkable and complex arrangement. There is, however, an internal membranous and epithelial lining, called the *endocardium;* and at the junction between the auricles and ventricles, the apertures of communication between their cavities, called the *auriculo-ventricular apertures*, are strengthened by *fibrous rings.* To these rings the moveable partitions, or *valves*, between the auricles and ventricles, the arrangement of which must next be considered, are attached.

10. There are three of these partitions attached to the circumference of the right auriculo-ventricular aperture, and two to that of the left (Figs. 11, 12, 13, 14, *t v*, *m v*). Each is a broad, thin, but very tough and strong triangular fold of connective tissue (see Lesson XII.) covered by endocardium, attached by its base, which joins on to its fellow, to the auriculo-ventricular fibrous ring, and hanging with its point downwards into the ventricular cavity. On the right side there are, therefore, three of these broad, pointed membranes, whence the whole apparatus is called the *tricuspid valve.* On the left side, there are but two, which, when detached from all their connexions but the auriculo-ventricular ring, look

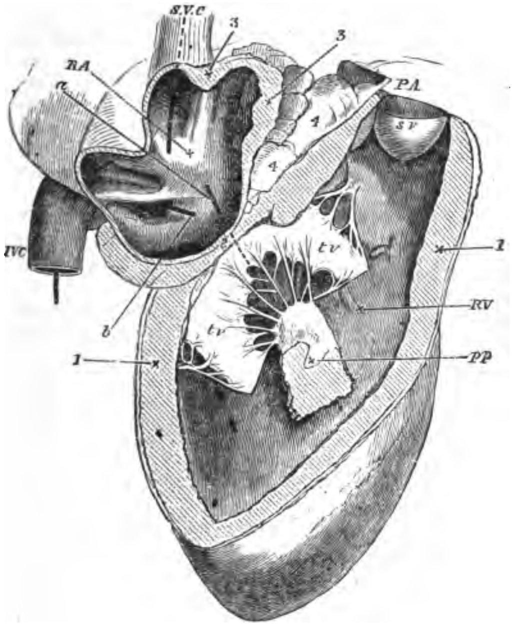

FIG. 11.—RIGHT SIDE OF THE HEART OF A SHEEP.

R.A. cavity of right auricle; *S.V.C.* superior vena cava; *I.V.C.* inferior vena cava; (a style has been passed through each of these;) *a*, a style passed from the auricle to the ventricle through the auriculo-ventricular orifice; *b*, a style passed into the coronary vein.

R.V. cavity of right ventricle; *tv*, *tv*, two flaps of the tricuspid valve: the third is dimly seen behind them, the style *a* passing between the three. Between the two flaps, and attached to them by *chordæ tendineæ*, is seen a papillary muscle, *pp*, cut away from its attachment to that portion of the wall of the ventricle which has been removed. Above, the ventricle terminates somewhat like a funnel in the pulmonary artery, *P.A.* One of the pockets of the semilunar valve, *sv*, is seen in its entirety, another partially.

1, the wall of the ventricle cut across; 2, the position of the auriculo-ventricular ring; 3, the wall of the auricle; 4, masses of fat lodged between the auricle and pulmonary artery.

something like a bishop's mitre, and hence bear the name of the *mitral valve.*

The edges and apices of the valves are not completely free and loose. On the contrary, a number of fine, but strong, tendinous cords, called *chordæ tendineæ*, connect them with some column-like elevations of the fleshy substance of the walls of the ventricle, which are termed *papillary muscles* (Figs. 11 and 12, *pp*); similar column-like elevations of the walls of the ventricles, but having no *chordæ tendineæ* attached to them, are called *columnæ carneæ.*

It follows, from this arrangement, that the valves oppose no obstacle to the passage of fluid from the auricles to the ventricles; but if any should be forced the other way, it will at once get between the valve and the wall of the heart, and drive the valve backwards and upwards. Partly because they soon meet in the middle and oppose one another's action, and partly because the *chordæ tendineæ* hold their edges and prevent them from going back too far, the valves, thus forced back, give rise to the formation of a complete transverse partition between the ventricle and the auricle, through which no fluid can pass.

Where the aorta opens into the next ventricle and where the pulmonary artery opens into the right ventricle, another valvular apparatus is placed, consisting in each case of three pouch-like valves called the *semilunar valves* (Fig. 11, *s.v.*; Figs. 13 and 14, *Ao. P.A.*), which are similar to those of the veins. Since they are placed on the same level and meet in the middle line, they completely stop the passage when any fluid is forced along the artery towards the heart. On the other hand, these valves flap back and allow any fluid to pass from the heart into the artery, with the utmost readiness.

The action of the auriculo-ventricular valves may be demonstrated with great ease on a sheep's heart, in which the aorta and pulmonary artery have been tied and the greater part of the auricles cut away, by pouring water into the ventricles through the auriculo-ventricular aperture. The tricuspid and mitral valves then usually become closed by the upward pressure of the water which gets behind them. Or, if the ventricles be nearly

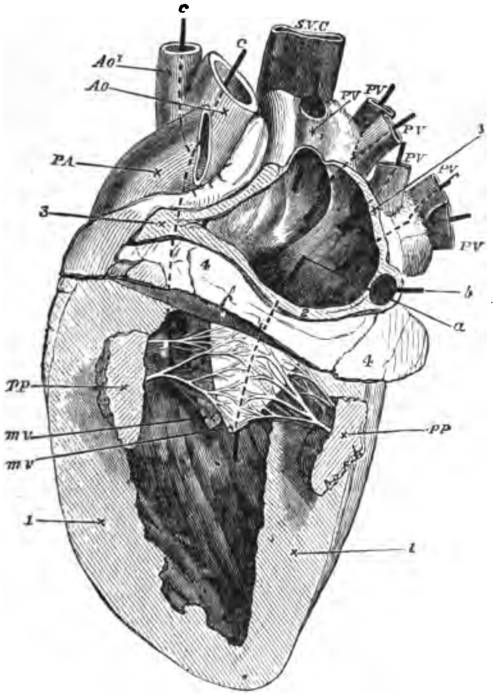

FIG. 12.—LEFT SIDE OF THE HEART OF A SHEEP (LAID OPEN).

P.V. pulmonary veins opening into the left auricle by four openings, as shown by the styles; *a*, a style passed from auricle into ventricle through the auriculo-ventricular orifice; *b*, a style passed into the coronary vein, which, though it has no connexion with the left auricle, is, from its position, necessarily cut across in thus laying open the auricle.

M.V. the two flaps of the mitral valve (drawn somewhat diagrammatically); *pp*, papillary muscles, belonging as before to the part of the ventricle cut away; *c*, a style passed from ventricle in *Ao.* aorta; *Ao*¹. branch of aorta (see Fig. 8, *A'o'*); *P.A.* pulmonary artery; *S.V.C.* superior vena cava.

1, wall of ventricle cut across; 2, wall of auricle cut away around auriculo-ventricular orifice; 3, other portions of auricular wall cut across; 4, mass of fat around base of ventricle (see Fig. 8, 2).

filled, the valves may be made to come together at once by gently squeezing the ventricles. In like manner, if the base of the aorta, or pulmonary artery, be cut out of the heart, so as not to injure the semilunar valves, water poured into the upper ends of the vessel will cause its valves to close tightly, and allow nothing to flow out after the first moment.

Thus the arrangement of the auriculo-ventricular valves is such, that any fluid contained in the chambers of the

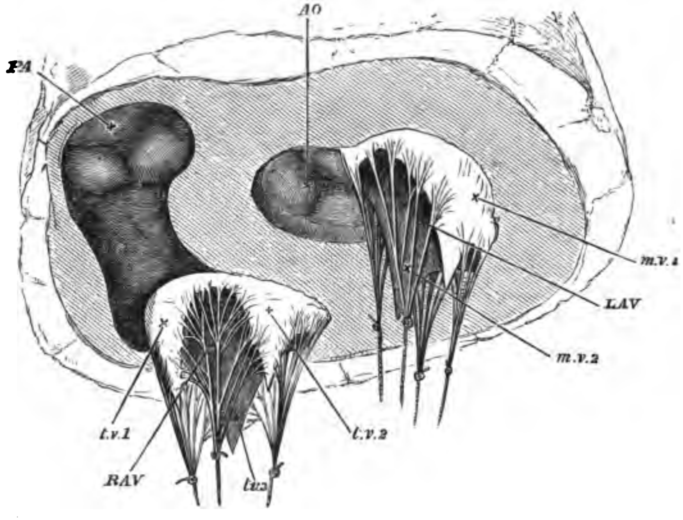

FIG. 13.—VIEW OF THE ORIFICES OF THE HEART FROM BELOW, THE WHOLE OF THE VENTRICLES HAVING BEEN CUT AWAY.

R.A.V. right auriculo-ventricular orifice surrounded by the three flaps, *t.v.* 1, *t.v.* 2, *t.v.* 3, of the tricuspid valve; these are stretched by weights attached to the *chordæ tendineæ*.

L.A.V. left auriculo-ventricular orifice surrounded in same way by the two flaps, *m.v.* 1, *m.v.* 2, of mitral valve; *P.A.* the orifice of pulmonary artery, the semilunar valves having met and closed together; *Ao.* the orifice of the aorta with its semilunar valves. The shaded portion, leading from *R.A.V.* to *P.A.*, represents the funnel seen in Fig. 11.

heart can be made to pass through the auriculo-ventricular apertures in one direction only: that is to say, from the auricles to the ventricles. On the other hand, the arrangement of the semilunar valves is such that the fluid contents of the ventricles pass easily into the aorta and pulmonary artery, while none can be made to travel the other way from the arterial trunks to the ventricles.

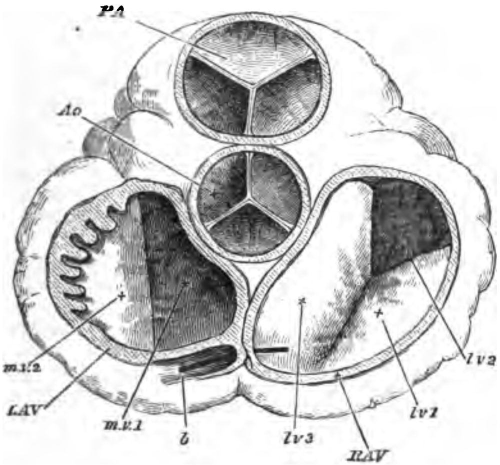

FIG. 14.—THE ORIFICES OF THE HEART SEEN FROM ABOVE, THE AURICLES AND GREAT VESSELS BEING CUT AWAY.

P.A. pulmonary artery, with its semilunar valves; *Ao.* aorta, do.
R.A.V. right auriculo-ventricular orifice with the three flaps (*l.v.* 1, 2, 3) of tricuspid valve.
L.A.V. left auriculo-ventricular orifice, with *m.v.* 1 and 2, flaps of mitral valve; *b*, style passed into coronary vein. On the left part of *L.A.V.*, the section of the auricle is carried through the auricular appendage; hence the toothed appearance due to the portions in relief cut across.

11. Like all other muscular tissues, the substance of the heart is contractile; but, unlike most muscles, the heart contains within itself a something which causes its different parts to contract in a definite succession and at regular intervals.

If the heart of a living animal be removed from the body, it will, though in most cases for a very short time only, go on pulsating much as it did while in the body. And careful attention to these pulsations will show that they consist of:—(1) A simultaneous contraction of the walls of both auricles. (2) Immediately following this, a simultaneous contraction of the walls of both ventricles. (3) Then comes a pause, or state of rest; after which the auricles and ventricles contract again in the same order as before, and their contractions are followed by the same pause as before.

If the auricular contraction be represented by $A^{\smile}$, the ventricular by $V^{\smile}$, and the pauses by —, the series of actions will be as follows: $A^{\smile}\,V^{\smile}$ —; $A^{\smile}\,V^{\smile}$ —; $A^{\smile}\,V^{\smile}$ —; &c. Thus, the contraction of the heart is *rhythmical*, two short contractions of its upper and lower halves respectively being followed by a pause of the whole, which occupies nearly as much time as the two contractions.

The state of contraction of the ventricle or auricle is called its *systole;* the state of relaxation, during which it undergoes dilatation, its *diastole.*

12. Having now acquired a notion of the arrangement of the different pipes and reservoirs of the circulatory system, of the position of the valves, and of the rhythmical contractions of the heart, it will be easy to comprehend what must happen if, when the whole apparatus is full of blood, the first step in the pulsation of the heart occurs and the auricles contract.

By this action each auricle tends to squeeze the fluid which it contains out of itself in two directions—the one towards the great veins, the other towards the ventricles; and the direction which the blood, as a whole, will take, will depend upon the relative resistance offered to it in these two directions. Towards the great veins it is resisted by the mass of the blood contained in the veins. Towards the ventricles, on the contrary, there is no resistance worth mentioning, inasmuch as the valves are open, the walls of the ventricles, in their uncontracted state, are flaccid and easily distended, and the entire pressure of the arterial blood is taken off by the semilunar valves, which are necessarily closed. The return of blood into

the veins is further checked by a contraction of the great veins which immediately precedes the systole of the auricles, and is practically continuous with it.

Therefore, when the auricles contract, little or none of the fluid which they contain will flow back into the veins; all the contents or nearly so will pass into and distend the ventricles. As the ventricles fill and begin to resist further distension, the blood, getting behind the auriculo-ventricular valves, will push them towards one another, and indeed almost shut them. The auricles now cease to contract, and immediately that their walls relax, fresh blood flows from the great veins and slowly distends them again.

But the moment the auricular systole is over, the ventricular systole begins. The walls of each ventricle contract vigorously, and the first effect of that contraction is to complete the closure of the auriculo-ventricular valves and so to stop all egress towards the auricle. The pressure upon the valves becomes very considerable, and they might even be driven upwards, if it were not for the *chordæ tendineæ* which hold down their edges.

As the contraction continues and the capacities of the ventricles become diminished, the points of the wall of the heart to which the *chordæ tendineæ* are attached approach the edges of the valves; and thus there is a tendency to allow of a slackening of these cords, which, if it really took place, might permit the edges of the valves to flap back and so destroy their utility. This tendency, however, is counteracted by the *chordæ tendineæ* being connected, not directly to the walls of the heart, but to those muscular pillars, the *papillary muscles*, which stand out from its substance. These muscular pillars shorten at the same time as the substance of the heart contracts; and thus, just so far as the contraction of the walls of the ventricles brings the *papillary muscles* nearer the valves, do they, by their own contraction, pull the *chordæ tendineæ* as tight as before.

By the means which have now been described, the fluid in the ventricle is debarred from passing back into the auricle; the whole force of the contraction of the ventricular walls is therefore expended in overcoming the resistance presented by the semilunar valves. This resistance

is partly the result of the mere weight of the vertical column of blood which the valves support ; but is chiefly due to the reaction of the distended elastic walls of the great arteries, for as we shall see, these arteries are already so full that the blood within them is pressing on their walls with great force.

It now becomes obvious why the ventricles have so much more to do than the auricles, and why valves are needed between the auricles and ventricles, while none are wanted between the auricles and the veins.

All that the auricles have to do is to fill the ventricles, which offer no active resistance to that process. Hence the thinness of the walls of the auricles, and hence the needlessness of any auriculo-venous valve, the resistance on the side of the ventricle being so insignificant that it gives way, at once, before the pressure of the blood in the veins.

On the other hand, the ventricles have to overcome a great resistance in order to force fluid into elastic tubes which are already full ; and if there were no auriculo-ventricular valves, the fluid in the ventricles would meet with less obstacle in pushing its way backward into the auricles and thence into the veins, than in separating the semilunar valves. Hence the necessity, firstly, of the auriculo-ventricular valves ; and, secondly, of the thickness and strength of the walls of the ventricles. And since the aorta, systemic arteries, capillaries, and veins form a system of tubes, which, from a variety of causes, offer more resistance than do the pulmonary arteries, capillaries, and veins, it follows that the left ventricle needs a thicker muscular wall than the right.

Thus, at every systole of the auricles, the ventricles are filled and the auricles emptied, the latter being slowly refilled by the pressure of the fluid in the great veins, which is amply sufficient to overcome the passive resistance of the relaxed auricular walls. And, at every systole of the ventricles, the arterial systems of the body and lungs receive the contents of these ventricles, and the emptied ventricles remain ready to be filled by the auricles.

13. We must now consider what happens in the arteries when the contents of the ventricles are suddenly forced into these tubes (which, it must be recollected, are already full).

If the vessels were tubes of a rigid material, like gas-pipes, the forcible discharge of the contents of the left ventricle into the beginning of the aorta would send a shock, travelling with great rapidity, right along the whole system of tubes, through the arteries into the capillaries, through the capillaries into the veins, and through these into the right auricle; and just as much blood would be driven from the end of the veins into the right auricle as had escaped from the left ventricle into the beginning of the aorta; and that, at almost the same instant of time. And the same would take place in the pulmonary vessels between the right ventricle and left auricle.

However, the vessels are not rigid, but, on the contrary, very yielding tubes; and the great arteries, as we have seen, have especially elastic walls. On the other hand, the friction in the capillaries and small arteries is so great that the blood cannot pass through them into the veins as quickly as it escapes from the ventricle into the aorta. Hence the contents of the ventricle, driven by the force of the systole past the semilunar valves, are at first lodged in the first part of the aorta, the walls of which are stretched and distended by the extra quantity of blood thus driven into it. But as soon as the ventricle has emptied itself and no more blood is driven out of it to stretch the aorta, the elastic walls of this vessel come into play; they strive to go back again and make the tube as narrow as it was before; thus they return back to the blood the pressure which they received from the ventricle. The effect of this elastic recoil of the arterial walls is on the one hand to close the semilunar valves, and so prevent the return of blood to the heart, and, on the other hand, to distend the next portion of the aorta, driving an extra quantity of blood into it. And this second portion, in a similar way, distends the next, and this again the next, and so on, right through the whole arterial system. Thus the impulse given by the ventricle travels like a wave along the arteries, distending them as it goes, and ultimately forcing the blood through the capillaries into the veins, and so on to the heart again.

14. Several of the practical results of the working of

the heart and arteries just described now become intelligible. For example, between the fifth and sixth ribs, on the left side, a certain movement is perceptible by the finger and by the eye, which is known as the *beating* of the heart. It is the result of the striking of the apex of the heart against the pericardium, and through it, on the inner wall of the chest, at this point, at the moment of the systole of the ventricles. Even when the heart is at rest, the apex, in a standing position, lies close under this part of the chest wall; and when the systole takes place, not only does the apex, like the rest of the ventricle, become firm and hard, but by the peculiar movements of the heart and great blood-vessels, is brought sharply in contact with the chest wall at this point. It is this sudden shove of the hardened apex which we feel and see, and which we call the beating, or more correctly the impulse, of the heart.

15. Secondly, if the ear be applied over the heart, certain *sounds* are heard, which recur with great regularity, at intervals corresponding with those between every two beats. First comes a longish dull sound; then a short sharp sound; then a pause; then the long, then the sharp sound, then another pause; and so on. There are many different opinions as to the cause of the first sound; some physiologists regard it as a muscular sound caused by the contraction of the muscular fibres of the ventricle, while others believe it to be due to the tension of the auriculo-ventricular valves; whatever be its exact cause it is given out at the same time that the ventricles contract. The second sound is, without doubt, caused by the sudden closure of the semilunar valves when the ventricular systole ends. That such is the case has been proved experimentally, by hooking back the semilunar valves in a living animal, when the second sound ceases at once.

16. Thirdly, if the finger be placed upon an artery, such as that at the wrist, what is termed the *pulse* will be felt; that is to say, the elastic artery dilates somewhat, at regular intervals, which answer to the beatings of the heart. The pulse which is felt by the finger, however, does not correspond in time precisely with the beat of the heart, but takes place a little after it, and the interval is longer the greater the distance of the artery from the heart.

The beat in the artery on the inner side of the ankle, for example, is a little later than the beat of the artery in the temple. The pulse is in fact nothing but that distension of the arterial walls of which we spoke just now, and which, travelling in the form of a wave from the larger to the smaller arteries, takes longer to reach and distend the more distant branch.

17. Fourthly, when an artery is cut, the outflow of the fluid which it contains is increased by *jerks*, the intervals of which correspond with the intervals of the beats of the heart. The cause of this is plainly the same as that of the pulse; the force which would be employed in distending the walls of the artery, were the latter entire, is spent in jerking the fluid out when the artery is cut.

18. Fifthly, under ordinary circumstances, the pulse is no longer to be detected in the capillaries, or in the veins. This arises from several circumstances. One of them is that the capacity of the branches of an artery is greater than the capacity of its trunk, and the capacity of the capillaries, as a whole, is greater than that of all the small arteries put together. Hence, supposing the capacity of the trunk to be 10, that of its branches 50, and that of the capillaries into which these open 100,[1] it is clear that a quantity of fluid thrown into the trunk, sufficient to dilate it by one-tenth, and to produce a very considerable and obvious effect, could not distend each branch by more than $\frac{1}{50}$th, and each capillary by $\frac{1}{100}$th of its volume, an effect which might be quite imperceptible.

19. But this is not all. Did the pulse merely become indistinguishable on account of its division and dispersion among so many capillaries, it might be felt again when the blood is once more gathered up into a few large venous trunks. But it is not. The pulse is definitely lost at the capillaries. There is, under ordinary circumstances, no pulse whatever in the veins, except sometimes a backward pulse from the heart along the great venous trunks; but this is quite another matter.

This actual loss, or rather transformation of the pulse,

[1] Ten and one hundred are here taken for simplicity's sake. As a matter of fact, the capacity of the capillaries is not only ten times, but several hundred times greater than that of the aorta.

is effected by means of the elasticity of the arterial walls, in the following manner.

In the first place it must be borne in mind that, owing to the minute size of the capillaries and small arteries, the amount of friction taking place in their channels when the blood is passing through them in very great; in other words, they offer a very great resistance to the passage of the blood. The consequence of this is, that, in spite of the fact that the total area of the capillaries is so much greater than that of the aorta, the blood has a difficulty in getting through the capillaries into the veins as fast as it is thrown into the arteries by the heart. The whole arterial system, therefore, becomes over-distended with blood.

Now we know by experiment that under such conditions as these, an elastic tube has the power, if long enough and elastic enough, to change a jerked impulse into a continuous flow.

If a syringe (or one of the elastic bottles now so frequently in use) be fastened to one end of a long glass tube, and water be pumped through the tube, it will flow from the far end in jerks, corresponding to the jerks of the syringe. This will be the case whether the tube be quite open at the far end, or drawn out to a fine point so as to offer great resistance to the outflow of the water. The glass tube is a rigid tube, and there is no elasticity to be brought into play.

If now a long india-rubber tube be substituted for the glass tube, it will be found to act differently, according as the opening at the far end is wide or narrow. If it is wide, the water flows out in jerks, nearly as distinct as those from the glass tube. There is little resistance to the outflow, little distension of the india-rubber tube, little elasticity brought into play. If, however, the opening be narrowed, as by fastening to it a stopcock or a glass tube drawn to a point, or if a piece of sponge be thrust into the end of the tube—if, in fact, in any way resistance be offered to the outflow of the water, the tube becomes distended, its elasticity is brought into play, and the water flows out from the end, not in jerks but in a stream, which is more and more completely continuous the longer and more elastic the tube.

Substitute for the syringe the heart, for the stopcock or

sponge the capillaries and small arteries, for the india-rubber tube the whole arterial system, and you have exactly the same result in the living body. Through the action of the elastic arterial walls the separate jets from the heart are blended into one continuous stream. The whole force of each blow of the heart is not at once spent in driving a quantity of blood through the capillaries; a part only is thus spent, the rest goes to distend the elastic arteries. But during the interval between that beat and the next the distended arteries are narrowing again, by virtue of their elasticity, and so are pressing the blood on into the capillaries with as much force as they were themselves distended by the heart. Then comes another beat, and the same process is repeated. At each stroke the elastic arteries shelter the capillaries from part of the sudden blow, and then quietly and steadily pass on that part of the blow to the capillaries during the interval between the strokes.

The larger the amount of elastic arterial wall thus brought into play, *i.e.* the greater the distance from the heart, the greater is the fraction of each heart's stroke which is thus converted into a steady elastic pressure between the beats. Thus the pulse becomes less and less marked the farther you go from the heart; any given length of the arterial system, so to speak, being sheltered by the lengths between it and the heart.

Every inch of the arterial system may, in fact, be considered as converting a small fraction of the heart's jerk into a steady pressure, and when all these fractions are summed up together in the total length of the arterial system no trace of the jerk is left.

As the immediate, sudden effect of each systole becomes diminished in the smaller vessels by the causes above mentioned, that of this constant pressure becomes more obvious, and gives rise to a steady passage of the fluid from the arteries towards the veins. In this way, in fact, the arteries perform the same functions as the air-reservoir of a fire-engine, which converts the jerking impulse given by the pumps into the steady flow of the delivery hose.

20. Such is the general result of the mechanical conditions of the organs of the circulation combined with the

rhythmical activity of the heart. This activity drives the fluid contained in these organs out of the heart into the arteries, thence to the capillaries, and from them through the veins back to the heart. And in the course of these operations it gives rise, incidentally, to the beating of the heart, the sounds of the heart, and the pulse.

It has been found, by experiment, that in the horse it takes about half a minute for any substance, as for instance a chemical body, whose presence in the blood can easily be recognized, to complete the circuit, *ex. gr.* to pass from the jugular vein down through the right side of the heart, the lungs, the left side of the heart, up through the arteries of the head and neck, and so back to the jugular vein.

By far the greater portion of this half minute is taken up by the passage through the capillaries, where the blood moves, it is estimated, at the rate only of about one and a half inches in a *minute*, whereas through the carotid artery of a dog it flies along at the rate of about ten inches in a *second*. Of course to complete the circuit of the circulation, a blood-corpuscle need not have to go through so much as half of an inch of capillaries in either the lungs or any of the tissues of the body.

Inasmuch as the force which drives the blood on is (putting the other comparatively slight helps on one side) the beat of the heart and that alone, however much it may be modified, as we have seen, in character, it is obvious that the velocity with which the blood moves must be greatest in the aorta and diminish towards the capillaries.

For with each branching of the arteries the total area of the arterial system is increased, the total width of the capillary tubes if they were all put together side by side being very much greater than that of the aorta. Hence the blood, or a corpuscle, for instance, of the blood being driven by the same force, viz. the heart's beat, over the whole body, must pass much more rapidly through the aorta than through the capillary system or any part of that system.

It is not that the greater friction in any capillary causes the blood to flow more slowly there and there only. The resistance caused by the friction in the

capillaries is thrown back upon the aorta, which indeed feels the resistance of the whole vascular system; and it is this total resistance which has to be overcome by the heart before the blood can move on at all.

The blood driven everywhere by the same force simply moves more and more slowly as it passes into wider and wider channels. When it is in the capillaries it is slowest; after escaping from the capillaries, as the veins unite into larger and larger trunks, and hence as the total venous area is getting less and less, the blood moves again faster and faster for just the same reason that in the arteries it moved slower and slower.

A very similar case is that of a river widening out in a plain into a lake and then contracting into a narrow stream again. The water is driven by one force throughout (that of gravity). The current is much slower in the lake than in the narrower river either before or behind.

21. It is now necessary to trace the exact course of the circulation as a whole. And we may conveniently commence with the portion of the blood contained at any moment in the right auricle. The contraction of the right auricle drives that fluid into the right ventricle; the ventricle then contracts and forces it into the pulmonary artery; from hence it passes into the capillaries of the lungs. Leaving these, it returns by the four pulmonary veins to the left auricle; and the contraction of the left auricle drives it into the left ventricle.

The systole of the left ventricle forces the blood into the aorta. The branches of the aorta convey it into all parts of the body except the lungs; and from the capillaries of all these parts, except from those of the stomach intestines and certain other viscera in the abdomen, it is conveyed, by vessels which gradually unite into larger and larger trunks, into either the superior or the inferior *vena cava*, which carry it to the right auricle once more.

But the blood brought to the capillaries of the stomach and intestines, spleen and pancreas, is gathered into veins which unite into a single trunk—the *vena portæ*. The vena portæ distributes its blood to the liver, mingling with that supplied to the capillaries of the same organ by

the hepatic artery. From these capillaries it is conveyed by small veins, which unite into a large trunk—the *hepatic vein*, which opens into the inferior vena cava. The flow of the blood from the abdominal viscera, through the liver, to the hepatic vein, is called the *portal circulation*.

The heart itself is supplied with blood by the two *coronary arteries* which spring from the root of the aorta just above two of the semilunar valves. The blood from the capillaries of the heart is carried back by the coronary vein, not to either vena cava, but to the right auricle. The opening of the coronary vein is protected by a valve, so as to prevent the right auricle from driving the venous blood which it contains back into the vessels of the heart.

22. Thus, the *shortest possible course* which any particle of the blood can take in order to pass from one side of the heart to the other, is to leave the aorta by one of the coronary arteries, and return to the right auricle by the coronary vein. And in order to pass through the *greatest possible number of capillaries* and return to the point from which it started, a particle of blood must leave the heart by the aorta and traverse the arteries which supply the alimentary canal, spleen and pancreas. It then enters 1stly, the capillaries of these organs; 2ndly, the capillaries of the liver; and, 3rdly, after passing through the right side of the heart, the capillaries of the lungs, from which it returns to the left side and eventually to the aorta.

Furthermore, from what has been said respecting the lymphatic system, it follows that any particle of matter which enters a lacteal of the intestine, will reach the right auricle by the superior cava, after passing through the lymph capillaries and channels of sundry lymphatic glands; while anything which enters the adjacent blood capillary in the wall of the intestine will reach the right auricle by the inferior cava, after passing through the blood capillaries of the liver.

23. It has been shown above (§ 2) that the small arteries may be directly affected by the nervous system, which controls the state of contraction of their muscular walls, and so regulates their calibre. The effect of this power of the nervous system is to give it a certain

control over the circulation in particular spots, and to produce such a state of affairs that, although the force of the heart and the general condition of the vessels remain the same, the state of the circulation may be very different in different localities.

Blushing is a purely local modification of the circulation of this kind, and it will be instructive to consider how a blush is brought about. An emotion, sometimes pleasurable, sometimas painful, takes possession of the mind ; thereupon a hot flush is felt, the skin grows red, and according to the intensity of the emotion these changes are confined to the cheeks only, or extend to the "roots of the hair," or "all over."

What is the cause of these changes? The blood is a red and a hot fluid ; the skin reddens and grows hot, because its vessels contain an increased quantity of this red and hot fluid ; and its vessels contain more, because the small arteries suddenly dilate, the natural moderate contraction of their muscles being superseded by a state of relaxation ; and this relaxation comes on because the action of the nervous system which previously kept the muscles in a state of moderate contraction is, for the time, suspended.

On the other hand, in many people, extreme terror causes the skin to grow cold, and the face to appear pale and pinched. Under these circumstances, in fact, the supply of blood to the skin is greatly diminished, in consequence of an increased contraction of the muscles of the small arteries whereby these become unduly narrowed or constricted, and thus allow only a small quantity of blood to pass through them ; and this increased contraction of the muscular coats of the arteries is brought about by the increased action of the nervous system.

24. That this is the real state of the case may be proved experimentally upon rabbits. These animals may be made to blush artificially. If, in a rabbit, the sympathetic nerve which sends branches to the vessels of the head is cut, the ear of the rabbit, which is covered by so delicate an integument that the changes in its vessels can be readily perceived, at once blushes. That is to say, the vessels dilate, fill with blood, and the ear becomes red and hot. The reason of this is, that when the sympathetic is cut,

the nervous stimulus which is ordinarily sent along its branches is interrupted, and the muscles of the small vessels, which were slightly contracted, become altogether relaxed.

And now it is quite possible to produce pallor and cold in the rabbit's ear. To do this it is only necessary to irritate the cut end of the sympathetic which remains connected with the vessels. The nerve then becomes excited, so that the muscular fibres of the vessels are thrown into a violent state of contraction, which diminishes their calibre so much that the blood can hardly make its way through them. Consequently, the ear becomes pale and cold.

25. The nerves which thus regulate the calibre of the small arteries by acting on their muscular coats are called *vaso-motor* nerves; and through them the nervous system is able to exert a local control over the circulation in any part or organ, the importance of which is very great. Thus, when an organ becomes active, it is of advantage that it should be more richly supplied with blood than when it is at rest. Accordingly we find that when a muscle contracts, or when a salivary gland secretes saliva, or when the stomach is preparing to digest food, in each case the small arteries of the muscle, salivary gland or stomach, dilate and so flush the part with blood. The organ in fact blushes; and this inner unseen blushing is, like the ordinary blushing described above, brought about by vaso-motor nerves. We shall see later on that the temperature of the body is largely regulated by the supply of blood sent to the skin to be cooled, and this supply is in turn regulated by the vaso-motor nervous system. Indeed everywhere all over the body, the nervous system by its vaso-motor nerves is continually supervising and regulating the supply of blood, sending now more now less blood, to this or that part; and many diseases, such as those when exposure to cold causes congestion or inflammation, are due to, or at least associated with, a disorder or failure of this vaso-motor activity.

26. Is the heart, in like manner, under the control of the central nervous system?

As we all know, it is not under the direct influence of

the will, but every one is no less familiar with the fact that the actions of the heart are wonderfully affected by all forms of emotion. Men and women often faint, and have sometimes been killed by sudden and violent joy or sorrow; and when they faint or die in this way, they do so because the perturbation of the brain gives rise to a something which arrests the heart as dead as you stop a stop-watch with a spring. On the other hand, other emotions cause that extreme rapidity and violence of action which we call palpitation.

Now the heart is well supplied with nerves. There are many small *ganglia*, or masses of nerve cells lodged in the substance of the heart, more especially in the auricles, and nerves spread from these ganglia over the walls, both of the auricles and ventricles. Moreover, several nerves reach the heart from the outside. Of these the most important perhaps are branches of a remarkable nerve which starts from the brain, and supplies not only the heart, but the lungs, alimentary canal, and other parts, and which is called the *pneumogastric*, or from its wandering course, the *vagus*. Other nerves reaching the heart seem to come from the sympathetic, but probably many of these may be traced back through the sympathetic to the spinal cord. There is every reason to believe that the regular rhythmical succession of the ordinary contractions of the heart depends in some way upon the ganglia lodged in its substance. At any rate, it is certain that these movements do not depend on any nerves outside the heart, since they go on even when the heart is removed from the body.

On the other hand the influence which arrests the heart's action, as in fainting, comes to the heart from without, and is carried to the heart by the pneumogastric. This may be demonstrated in animals, such as frogs, with great ease.

27. If a frog be pithed, or its brain destroyed, so as to obliterate all sensibility, the animal will continue to live, and its circulation will go on perfectly well for an indefinite period. The body may be laid open without causing pain or other disturbance, and then the heart will be observed beating with great regularity. It is possible to make the heart move a long index backwards

and forwards; and if frog and index are covered with a glass shade, the air under which is kept moist, the index will vibrate with great steadiness for a couple of days.

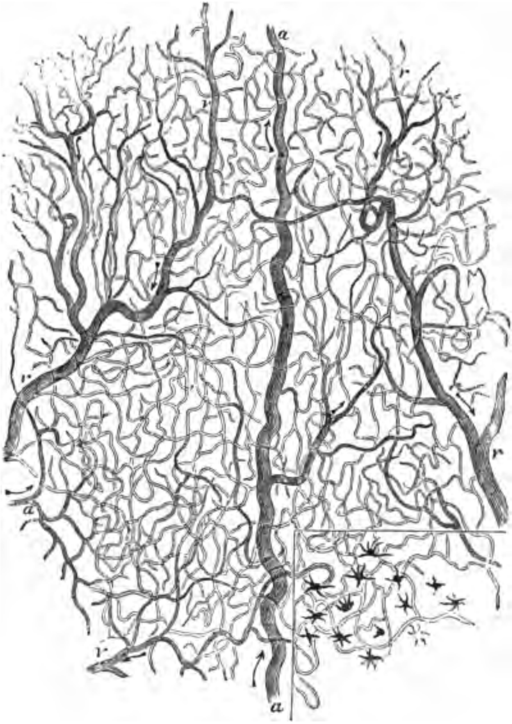

FIG. 15.—Portion of the web of a frog's foot seen under a low magnifying power, the blood-vessels only being represented, except in the corner of the field, where in the portion marked off the pigment spots are also drawn.

a. small arteries; *v*. small veins: the minute tubes joining the arteries of the veins are the capillaries. The arrows denote the direction of the circulation. The larger artery running straight up in the middle line breaks up into capillaries at points higher up than can be shown in the drawing.

It is easy to adjust to the frog thus prepared a contrivance by which electrical shocks may be sent through the pneumogastric nerves, so as to irritate them. The moment this is done the index stops dead, and the heart will be found quiescent, with relaxed and distended walls. After a little time the influence of the pneumogastric passes off, the heart recommences its work as vigorously as before, and the index vibrates through the same arc as formerly. With careful management, this experiment may be repeated very many times; and after every arrest by the irritation of the pneumogastric, the heart resumes its work. When a person faints from a sudden emotion, a similar influence, started in the brain, descends along the pneumogastric, and similarly stops for a while the beating of the heart.

The exact manner in which palpitation is brought about does not seem so clear; in such cases an influence of some kind probably reaches the heart along nerves which for a part of their course run along with the sympathetic nerves; but this subject requires further investigation.

28. The evidence that the blood circulates in man, although perfectly conclusive, is almost all indirect. The most important points in the evidence are as follows:—

In the first place, the disposition and structure of the organs of circulation, and more especially the arrangement of the various valves, will not, as was shown by Harvey, permit the blood to flow in any other direction than in the one described above. Moreover, we can easily with a syringe inject a fluid from the vena cava, for instance, through the right side of the heart, the lungs, the left side of the heart, the arteries, and capillaries, back to the vena cava; but not the other way. In the second place, we know that in the living body the blood is continually flowing in the arteries towards the capillaries, because when an artery is tied, in a living body, it swells up and pulsates on the side of the ligature nearest the heart, whereas on the other side it becomes empty, and the tissues supplied by the artery become pale from the want of a supply of blood to their capillaries. And when we cut an artery the blood is pumped out in jerks from the cut end nearest the heart, whereas little or no blood comes from the other end. When, however, we tie a vein

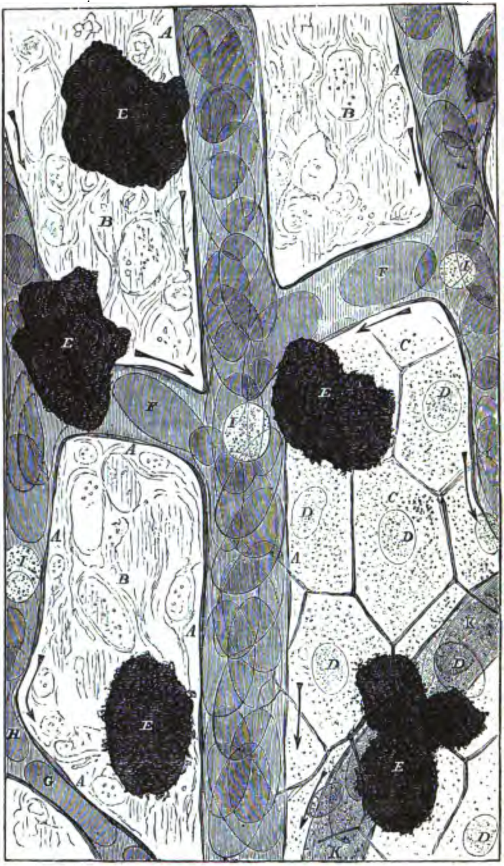

FIG. 16.—Very small portion of Fig. 15 very highly magnified.

A. walls of capillaries; *B*. tissue of web lying between the capillaries; *C*. cells of epidermis covering web (these are only shown in the right-hand

the state of things is reversed, the swelling taking place on the side farthest from the heart, &c. &c., showing that in the veins the blood flows from the capillaries to the heart.

But certain of the lower animals, the whole, or parts, of the body of which are transparent, readily afford direct proof of the circulation; in these the blood may be seen rushing from the arteries into the capillaries, and from the capillaries into the veins, so long as the animal is alive and its heart is at work. The animal in which the circulation can be most conveniently observed is the frog. The web between its toes is very transparent, and the particles suspended in its blood are so large that they can be readily seen as they slip swiftly along with the stream of blood, when the toes are fastened out, and the intervening web is examined under even a low magnifying power (Figs. 15 and 16).

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and lower part of the field; in the other parts of the field the focus of the microscope lies below the epidermis); *D.* nuclei of these epidermic cells; *E.* pigment cells contracted, not partially expanded as in Fig. 15; *F.* red blood-corpuscle (oval in the frog) passing along capillary—nucleus not visible; *G.* another corpuscle squeezing its way through a capillary, the canal of which is smaller than its own transverse diameter; *H.* another bending as it slides round a corner; *K.* corpuscle in capillary seen through the epidermis; *I.* white blood-corpuscle.

LESSON III.

THE BLOOD AND THE LYMPH.

1. IN order to become properly acquainted with the characters of the blood it is necessary to examine it with a microscope magnifying at least three or four hundred diameters. Provided with this instrument, a hand lens, and some slips of thick and thin glass, the student will be enabled to follow the present lesson.

The most convenient mode of obtaining small quantities of blood for examination is to twist a piece of string, pretty tightly, round the middle of the last joint of the middle, or ring finger, of the left hand. The end of the finger will immediately swell a little, and become darker coloured, in consequence of the obstruction to the return of the blood in the veins caused by the ligature. When in this condition, if it be slightly pricked with a sharp clean needle (an operation which causes hardly any pain), a good-sized drop of blood will at once exude. Let it be deposited on one of the slips of thick glass, and covered lightly and gently with a piece of the thin glass, so as to spread it out evenly into a thin layer. Let a second slide receive another drop, and, to keep it from drying, let it be put under an inverted watch-glass or wine-glass, with a bit of wet blotting-paper inside. Let a third drop be dealt with in the same way, a few granules of common salt being first added to the drop.

2. To the naked eye the layer of blood upon the first slide will appear of a pale reddish colour, and quite clear and homogeneous. But on viewing it with even a pocket lens its apparent homogeneity will disappear, and it will

look like a mixture of excessively fine yellowish-red particles, like sand, or dust, with a watery, almost colourless, fluid. Immediately after the blood is drawn, the particles will appear to be scattered very evenly through the fluid, but by degrees they aggregate into minute patches, and the layer of blood becomes more or less spotty.

The "particles" are what are termed the *corpuscles* of the blood; the nearly colourless fluid in which they are suspended is the *plasma*.

The second slide may now be examined. The drop of blood will be unaltered in form, and may perhaps seem to have undergone no change. But if the slide be inclined, it will be found that the drop no longer flows; and, indeed, the slide may be inverted without the disturbance of the drop, which has become solidified, and may be removed, with the point of a penknife, as a gelatinous mass. The mass is quite soft and moist, so that this setting, or *coagulation*, of a drop of blood is something very different from its drying.

On the third slide, this process of coagulation will be found not to have taken place, the blood remaining as fluid as it was when it left the body. The salt therefore, has prevented the coagulation of the blood. Thus this very simple investigation teaches that blood is composed of a nearly colourless plasma, in which many coloured corpuscles are suspended; that it has a remarkable power of coagulating; and that this coagulation may be prevented by artificial means, such as the addition of salt.

3. If, instead of using the hand lens, the drop of blood on the first slide be placed under the microscope, the particles, or corpuscles, of the blood will be found to be bodies with very definite characters, and of two kinds, called respectively the *red corpuscles* and the *colourless corpuscles*. The former are much more numerous than the latter, and have a yellowish-red tinge; when one of these corpuscles is seen, under a high power of the microscope, lying by itself, it seems to be hardly more than faintly yellow in colour, but when several are seen lying one on the other, the redness becomes obvious. The latter, somewhat larger than the red corpuscles, are, as their name implies, pale and devoid of coloration.

4. The corpuscles differ also in other and more

important respects. The *red corpuscles* (Fig. 17) are flattened circular disks, on an average $\frac{1}{3200}$th of an inch in diameter, and having about one-fourth of that thickness. It follows that rather more than 10,000,000 of them will

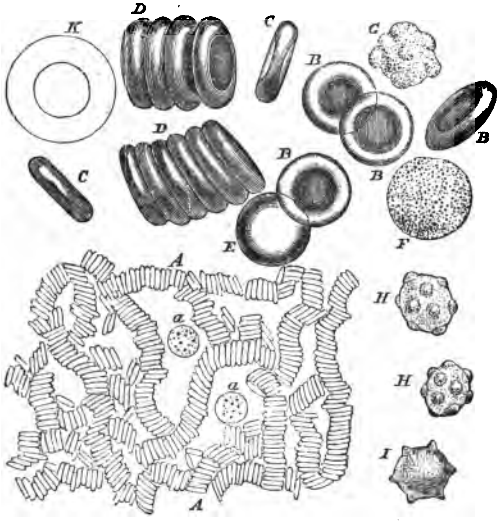

FIG. 17.—RED AND WHITE CORPUSCLES OF THE BLOOD MAGNIFIED.

A. Moderately magnified. The red corpuscles are seen lying in rouleaux; at *a* and *a* are seen two white corpuscles.
B. Red corpuscles much more highly magnified, seen in face; *C*. ditto, seen in profile; *D*. ditto, in rouleaux, rather more highly magnified; *E*. a red corpuscle swollen into a sphere by imbibition of water.
F. A white corpuscle magnified same as *B*.; *G*. ditto, throwing out some blunt processes; *K*. ditto, treated with acetic acid, and showing nucleus magnified same as *D*.
II. Red corpuscles puckered or crenate all over.
/. Ditto, at the edge only.

lie on a space one inch square, and that the volume of each corpuscle does not exceed $\frac{1}{120000000000}$th of a cubic inch.

The broad faces of the disks are not flat, but somewhat concave, as if they were pushed in towards one another. Hence the corpuscle is thinner in the middle than at the edges, and when viewed under the microscope, by transmitted light, looks clear in the middle and darker at the edges, or dark in the middle and clear at the edges, according as it is or is not in focus. When, on the other hand, the disks roll over and present their edges to the eye, they look like rods. All these varieties of appearance may be made intelligible by turning a round biscuit or muffin, bodies more or less similar in shape to the red corpuscles, in various ways before the eye.

The red corpuscles are very soft, flexible, and elastic bodies, so that they readily squeeze through apertures and passages narrower than their own diameters, and immediately resume their proper shapes (Fig. 16, *G.H.*). Examined under even a high power the red corpuscle presents no very obvious structure ; when however blood is frozen and thawed one or more times, or when it is treated in certain other ways, the colouring matter which gave each corpuscle its yellow or yellowish red tinge is dissolved out and passes into the plasma, and all that is left of the corpuscle is a colourless framework appearing often under the microscope as a pale, hardly visible, ring. Each corpuscle in fact consists of a sort of spongy colourless framework composed of the kind of material known as *proteid* (see lesson I. § 4) and of a peculiar colouring matter, which, in the natural condition, is intimately connected with this framework but may, by appropriate means be removed from it. This colouring matter, which is of a highly complex nature, is called *haemoglobin* and may, by proper chemical treatment be resolved into a reddish brown substance containing iron, called *haematin*, and a colourless proteid substance.

Each corpuscle therefore is not to be considered as a bag or sack with a definite skin or envelope containing fluid, but rather as a sort of spongy semi-solid or semi-fluid mass, like a disc of soft jelly ; and as such is capable of imbibing water and swelling up, or giving out water and shrinking according to the density of the fluid in which it may be placed. Thus, if the plasma of blood be made denser by dissolving saline substances, or sugar, in it,

water is drawn from the substance of the corpuscle to the dense plasma, and the corpuscle becomes still more flattened and very often much wrinkled. On the other hand, if the plasma be diluted with water, the latter forces itself into and dilutes the substance of the corpuscle, causing the latter to swell out, and even become spherical; and, by adding dense and weak solutions alternately, the corpuscles may be made to become successively spheroidal and discoidal. Exposure to carbonic acid gas seems to cause the corpuscles to swell out; oxygen gas, on the contrary, appears to flatten them.

5. The *colourless corpuscles* (Fig. 17, *a a*, *F. G. K.*) are larger than the red corpuscles, their average diameter being $\frac{1}{2500}$th of an inch. They are further seen, at a glance, to differ from the red corpuscles by the extreme irregularity of their form, and by their greater stickiness or adhesiveness, shown by their tendency to attach themselves to the glass slide, while the red corpuscles float about and tumble freely over one another.

A still more remarkable feature of the colourless corpuscles than the irregularity of their form is the unceasing variation of shape which they exhibit so long as they are alive. The form of a red corpuscle is changed only by influences from without, such as pressure, or the like; that of the colourless corpuscle is undergoing constant alteration, as the result of changes taking place in its own substance. To see these changes well, a microscope with a magnifying power of five or six hundred diameters is requisite; and, even then, they are so gradual that the best way to ascertain their existence is to make a drawing of a given colourless corpuscle at intervals of a minute or two. This is what has been done with the corpuscle represented in Fig. 18, in which *a* represents the form of the corpuscle when first observed; *b*, its form a minute afterwards; *c*, that at the end of the second; *d*, that at the end of the third; and *e*, that at the end of the fifth minute.

Careful watching of a colourless corpuscle, in fact, shows that every part of its surface is constantly changing —undergoing active contraction or being passively dilated by the contraction of other parts. It exhibits *contractility* in its lowest and most primitive form.

6. While they are thus living and active, a complete knowledge of the structure of the colourless corpuscles cannot be arrived at. Each corpuscle seems to be formed simply of a mass of the finely or coarsely granular substance called protoplasm in which no distinction of parts can be seen. This is especially the case when the corpuscle is at rest and assumes a spheroidal shape. Sometimes, however, the corpuscle in the course of the movements just described, spreads itself out into a very thin flat film; and when that is the case there may be seen in its interior a rounded body, differing in appearance from the rest of the body of corpuscle. Again when a drop of blood is diluted with water, still better with very dilute acetic acid, the spongy protoplasm of the white corpuscles swells up and becomes transparent,

FIG. 18.—SUCCESSIVE FORMS ASSUMED BY COLOURLESS CORPUSCLES OF HUMAN BLOOD. (Magnified about 600 diameters.)

The intervals between the forms *a*,*b*,*c*,*d*, was a minute; between *d* and *e* two minutes; so that the whole series of changes from *a* to *e* took five minutes.

many of the granules becoming dissolved, and in this case the same rounded body becomes visible. This internal rounded body, which differs in nature from the rest of the substance of the corpuscles is called the *nucleus* (Fig. 17, *K*); and when the blood is treated under the microscope, with various staining fluids, such as solutions of carmine or logwood, the nucleus generally stains more deeply than the rest of the corpuscle.

The colourless corpuscle, with its nucleus, is what is called a *nucleated cell.* It will be observed that it lives in a free state in the plasma of the blood, and that it exhibits an independent contractility. In fact, except that it is dependent for the conditions of its existence upon the plasma, it might be compared to one of those simple organisms which are met with in stagnant water, and are called *Amœbæ.*

7. But while the colourless corpuscles are thus nucleated cells, the red corpuscles have no such nucleus; and this is true not only of human blood but of the blood of all mammals, *i.e.* of all those animals which suckle their young; in all these the red corpuscle has no nucleus. In the case of birds, reptiles and fishes, however, the red corpuscles as well as the colourless are nucleated; and in the embryos[1] even of mammals the red corpuscles are at first nucleated.

The exact number of both red and colourless corpuscles present in the blood varies a good deal from time to time; and there is reason to think that both kinds of corpuscles are continually being destroyed or made use of, their place being supplied by new corpuscles. Further, there is reason to think that colourless corpuscles are formed, in part at least, in the lymphatic glands, from whence they pass through the lymphatic vessels into the blood, and that the red corpuscles are formed, probably in particular parts of the body, by the formation of hæmoglobin in cells which previously contained no such colouring matter. But whether the cells which give rise to red corpuscles are ordinary white corpuscles or a particular kind of cell, and how it is that the mammalian red corpuscle comes to have no nucleus, are questions, not as yet definitely decided.

8. As the blood dies, its several constituents, which have now been described, undergo marked changes.

The *colourless corpuscles* lose their contractility, but otherwise undergo little alteration. They tend to cohere neither with one another, nor with the red corpuscles, but adhere to the glass plate on which they are placed.

It is quite otherwise with the *red corpuscles*, which at first, as has been said, float about and roll, or slide, over each other quite freely. After a short time (the length of which varies in different persons, but usually amounts to two or three minutes), they seem, as it were, to become sticky, and tend to cohere; and this tendency increases until, at length, the great majority of them become applied face to face, so as to form long series, like rolls of coin. The end of one roll cohering with the sides of another,

[1] An embryo is the rudimentary unborn young of any creature.

a network of various degrees of closeness is produced (Fig. 17, *A.*).

The corpuscles remain thus coherent for a certain length of time, but eventually separate and float freely again. The addition of a little water, or dilute acids or saline solutions, will at once cause the rolls to break up.

It is from this running of the corpuscles together into patches of network that the change noted above in the appearances of the layer of blood, viewed with a lens. arises. So long as the corpuscles are separate, the sandy appearance lasts; but when they run together, the layer appears patchy or spotted.

The red corpuscles rarely, if ever, all run together into rolls, some always remaining free in the meshes of the net. In contact with air, or if subjected to pressure, many of the red corpuscles become covered with little knobs, so as to look like minute mulberries—an appearance which has been mistaken for a breaking up, or spontaneous division, of the corpuscles (Fig. 17, *H. H.*).

9. There is a still more remarkable change which the red blood-corpuscles occasionally undergo. Under certain circumstances, the peculiar red substance which gives them their colour, and indeed forms the chief part of their mass, and which has been called *hæmoglobin* (§ 4), separates in a crystalline form. In man, these crystals have the shape of prisms; in different animals they take different forms. Human blood crystallizes with difficulty, but that of the guinea-pig, rat, or dog much more easily.

If a little rat's or dog's blood, from which the fibrin has been removed, be shaken up with a little ether, and allowed to stand in the cold for some hours, a sediment will frequently form at the bottom; and this sediment when examined with the microscope, will be found to consist chiefly of long narrow *blood-crystals.*

10. When the layer of blood has been drawn ten or fifteen minutes, the plasma will be seen to be no longer clear. It then exhibits multitudes of extremely delicate filaments of a substance called *Fibrin*, which have been formed in it, and which traverse it in all directions, uniting with one another and with the corpuscles, and binding the whole into a semi-solid mass.

It is this formation of fibrin which is the cause of

the apparent solidification, or coagulation, of the drop upon the second slide; but the phenomena of coagulation, which are of very great importance, cannot be properly understood until the behaviour of the blood, when drawn in larger quantity than a drop, has been studied.

11. When, by the ordinary process of opening a vein with a lancet, a quantity of blood is collected into a basin, it is at first perfectly fluid: but in a very few minutes it becomes, through coagulation, a jelly-like mass, so solid that the basin may be turned upside down without any of the blood being spilt. At first the clot is a uniform red jelly, but very soon drops of a clear yellowish watery-looking fluid make their appearance on the surface of the clot, and on the sides of the basin. These drops increase in number, and run together, and after a while it has become apparent that the originally uniform jelly has separated into two very different constituents—the one a clear, yellowish liquid; the other a red, semi-solid mass, which lies in the liquid, and at the surface is sometimes paler in colour and firmer than in its deeper part.

The liquid is called the *serum;* the semi-solid mass the clot, or *crassamentum.* Now the clot obviously contains the corpuscles of the blood, bound together by some other substance; and this last, if a small part of the clot be examined microscopically, will be found to be that fibrous-looking matter, *fibrin*, which has been seen forming in the thin layer of blood. Thus the clot is equivalent to the corpuscles *plus* the fibrin of the plasma, while the serum is the plasma *minus* the fibrinous elements which it contained.

12. The corpuscles of the blood are slightly heavier than the plasma, and therefore, when the blood is drawn, they sink very slowly towards the bottom. Hence the upper part of the clot is apt to contain fewer corpuscles, and to be lighter in colour, than the lower part—there being fewer corpuscles left in the upper layer of plasma for the fibrin to catch when it sets. When the blood clots slowly, the corpuscles have so much time to sink that the upper stratum of plasma becomes quite free from red corpuscles before the fibrin forms in it; and, consequently, the uppermost layer of the clot is nearly white:

it then receives the name of the *buffy coat.* This is well seen in the blood of the horse. Sometimes the rapid sinking of the corpuscles and hence the appearance of the buffy coat appears to be due to some conditions of the blood causing the corpuscles to run together much more closely and in denser masses than usual, whereby they more readily overcome the resistance of the plasma to their falling, just as feathers stuck together in masses fall much more rapidly through the air than the same feathers when loose.

After the clot is formed, the fibrin shrinks and squeezes out much of the serum contained within its meshes; and, other things being equal, it contracts the more the fewer corpuscles there are in the way of its shrinking. Hence, when the buffy coat is formed, it usually contracts so much as to give the clot a cup-like upper surface.

Thus the buffy coat is fibrin naturally separated from the red corpuscles; the same separation may be effected, artificially, by whipping the blood with twigs as soon as it is drawn, until its coagulation is complete. Under these circumstances the fibrin will collect upon the twigs, and a red fluid will be left behind, consisting of the serum *plus* the red corpuscles, and many of the colourless ones.

13. The coagulation of the blood is hastened, retarded, or temporarily prevented by many circumstances.

(*a*) *Temperature.*—A high temperature accelerates the coagulation of the blood; a low one retards it very greatly; so much so that blood kept at a temperature close to freezing point, may remain fluid for a very long time indeed.

(*b*) *The addition of saline matters to the blood.*—Many saline substances, and more especially sulphate of soda and common salt, dissolved in the blood in sufficient quantity, prevent its coagulation; but coagulation sets in when water is added, so as to dilute the saline solution.

(*c*) *Contact with living or not living matter.*—Contact with not living matter promotes the coagulation of the blood. Thus, blood drawn into a basin begins to coagulate first where it is in contact with the sides of the basin; and a wire introduced into a living vein will become coated with fibrin, although perfectly fluid blood surrounds it.

On the other hand, direct contact with living matter retards, or altogether prevents, the coagulation of the blood. Thus blood remains fluid for a very long time in a portion of a vein which is tied at each end. The heart of a turtle remains alive for a lengthened period (many hours or even days) after it is extracted from the body; and, so long as it remains alive, the blood contained in it will not coagulate, though, if a portion of the same blood be removed from the heart, it will coagulate in a few minutes. Blood taken from the body of the turtle, and kept from coagulating by cold for some time, may be poured into the separated, but still living, heart, and then will not coagulate.

Freshly deposited fibrin acts somewhat like living matter, coagulable blood remaining fluid for a long time in tubes coated with such fibrin.

14. The coagulation of the blood is an altogether physico-chemical process, dependent upon the properties of certain of the constituents of the plasma, apart from the vitality of that fluid. This is proved by the fact that if common table salt be gradually added to freshly-drawn blood which has not yet coagulated, or to blood plasma which has been kept from coagulating by cold, a white, flocculent, somewhat viscid substance is thrown down or precipitated as soon as sufficient salt has been added. The substance so thrown down may be separated by filtration, and purified by washing with a concentrated solution of salt, in which it is insoluble. It is not fibrin, for whereas fibrin is characteristically insoluble, this substance is readily soluble in distilled water, giving a clear limpid solution. But this solution does not long remain so; unless special precautions, such as exposing to cold, &c., be taken, it soon becomes viscid, then turns into a jelly, and at last forms an unmistakable clot of true fibrin. The substance in question is therefore an antecedent of fibrin, which, by some changes or other, is converted into fibrin; that is to say, the coagulation of blood is due to the conversion of this soluble antecedent of fibrin into insoluble fibrin.

The exact nature of the changes involved in this conversion have not even yet been thoroughly worked out; but the following facts deserve attention:—The peri-

cardium and other serous cavities in the body contain a clear fluid, which may be briefly described as consisting of the elements of the blood without the red blood-corpuscles. This fluid sometimes coagulates spontaneously, as the blood plasma would do, but very often shows no disposition to spontaneous coagulation. When the latter is the case, the fluid may nevertheless be made to coagulate, and yield a true fibrinous clot, by adding to it a few drops of whipped blood, *i.e.* of blood which has coagulated, or a little serum of blood. Now if a specimen of pericardial fluid, which has been thus observed not to clot spontaneously, but to clot readily on the addition of blood or serum, be treated with salt in the same way as described above for blood plasma, a substance will be thrown down, which, at first sight, looks exactly like that thrown down from blood plasma. But there is a great difference, for the substance thus obtained from pericardial fluid when dissolved in water will not clot spontaneously, though its solutions may be made to clot at any time by the addition of a little serum, or whipped blood. It too may therefore be spoken of as an antecedent of fibrin, and indeed it has received the name of *fibrinogen*, or "fibrin maker." It is undoubtedly present in the substance thrown down by salt from blood plasma, but then it is mixed with other bodies; and the presence of some or other of these bodies seems to be the reason why in this case it is converted into fibrin, and so gives a clot. Conversely the absence of this body or these bodies from pericardial fluid is the reason why pericardial fluid, or fibrinogen prepared from pericardial fluid, does not clot spontaneously.

Besides fibrinogen there is present in blood plasma, and thrown down like it by salt, a very similar body which has been called globulin, or paraglobulin; and it is thought by many that fibrinogen is converted into fibrin by some inter-action between it and paraglobulin. But serious objections have been urged against this view, which cannot be regarded as definitely proved. Moreover, there are reasons for thinking that in the conversion of fibrinogen into fibrin an important part is played by the presence in shed blood in very small quantities of a body belonging to a remarkable class of substances called

"ferments," of which we shall have to speak when we come to consider digestion. These ferments are characterized by their power, even when present in small quantities, of producing great changes in other bodies without themselves entering into the changes. Thus the particular ferment of which we are speaking, and which has been called "fibrin ferment," produces fibrin, and yet does not itself become part of the fibrin so produced.

We may say then that fibrin as such does not exist in the blood at the moment of its being shed, but makes its appearance afterwards on account of the action of fibrin ferment on fibrinogen, other bodies as well being possibly concerned in the matter.

15. The proverb that "blood is thicker than water" is literally true, as the blood is not only "thickened" by the corpuscles, of which it has been calculated that no fewer than 70,000,000,000 (eighty times the number of the human population of the globe) are contained in a cubic inch, but is rendered slightly viscid by the solid matters dissolved in the plasma. The blood is thus rendered heavier than water, its specific gravity being about 1·055. In other words, twenty cubic inches of blood have about the same weight as twenty-one cubic inches of water.

The corpuscles are heavier than the plasma, and their volume is usually somewhat less than that of the plasma. Of colourless corpuscles there are usually not more than three or four for every thousand of red corpuscles; but the proportion varies very much, increasing shortly after food is taken, and diminishing in the intervals between meals.

The blood is hot, its temperature being about 100° Fahrenheit.

16. Considered chemically, the blood is an alkaline fluid, consisting of water, of solid and of gaseous matters.

The proportions of these several constituents vary according to age, sex, and condition, but the following statement holds good on the average:—

In every 100 parts of the blood there are 79 parts of water and 21 parts of dry solids; in other words, the water and the solids of the blood stand to one another in about the same proportion as the nitrogen and the oxygen of the air. Roughly speaking, one quarter of the blood

is dry, solid matter; three quarters water. Of the 21 parts of dry solids, 12 ($=\frac{4}{7}$ths) belong to the corpuscles. The remaining 9 are about two-thirds (6·7 parts $=\frac{3}{7}$ths) albumin (a substance like white of egg, coagulating by heat), and one-third ($=\frac{1}{7}$th of the whole solid matter) a mixture of saline, fatty, and saccharine matters, sundry products of the waste of the body, and fibrin. The quantity of the latter constituent is remarkably small in relation to the conspicuous part it plays in the act of coagulation. Healthy blood, in fact, yields in coagulating not more than from two to four parts in a thousand of its weight of fibrin.

The total quantity of gaseous matter contained in the blood is equal to rather more than half the *volume* of the blood; that is to say, 100 cubic inches of blood will contain about 60 cubic inches of gases. These gaseous matters are carbonic acid, oxygen, and nitrogen; or, in other words, the same gases as those which exist in the atmosphere, but in totally different proportions; for whereas air contains nearly three-fourths nitrogen, one-fourth oxygen, and a mere trace of carbonic acid, the average composition of the blood gases is about two-thirds or more carbonic acid, and one-third or less oxygen, the quantity of nitrogen being exceedingly small.

It is important to observe that blood contains much more oxygen gas than could be held in solution by pure water at the same temperature and pressure. This power of holding oxygen appears in some way to depend upon the corpuscles, firstly, because mere serum has no greater power of absorbing oxygen than pure water has; and secondly, because red corpuscles suspended in water instead of serum absorb oxygen very readily. The oxygen thus held by the red corpuscles is readily given up by them for purposes of oxidation, and indeed can be removed from them by means of a mercurial gas pump. It would appear that the connection between the oxygen and the red corpuscles is of a peculiar nature, being a sort of loose chemical combination with one of their constituents, that constituent being the hæmoglobin; for solutions of hæmoglobin behave towards oxygen almost exactly as blood does. Similarly the blood contains more carbonic acid than could be held in solution by pure

water at the same temperature and pressure. But unlike the oxygen, the carbonic acid thus held by blood is not peculiarly associated with the hæmoglobin of the red corpuscles; in fact it seems to be chiefly retained by some constituents of the serum.

The corpuscles differ chemically from the plasma, in containing a large proportion of the fats and phosphates, all the iron, and almost all the potash, of the blood; while the plasma, on the other hand, contains by far the greater part of the chlorine and the soda.

17. The blood of adults contains a larger proportion of solid constitutents than that of children, and that of men more than that of women; but the difference of sex is hardly at all exhibited by persons of flabby, or what is called lymphatic, constitution.

Animal diet tends to increase the quantity of the red corpuscles; a vegetable diet and abstinence to diminish them. Bleeding exercises the same influence in a still more marked degree, the quantity of red corpuscles being diminished thereby in a much greater proportion than that of the other solid constituents of the blood.

18. The total quantity of blood contained in the body varies at different times, and the precise ascertainment of its amount is very difficult. It may probably be estimated, on the average, at not less than one-thirteenth of the weight of the body.

19. The function of the blood is to supply nourishment to, and take away waste matters from, all parts of the body. All the various tissues may be said to live on the blood. From it they obtain all the matters they need, and to it they return all the waste material for which they have no longer any use. It is absolutely essential to the life of every part of the body that it should be in such relation with a current of blood, that matters can pass freely from the blood to it, and from it to the blood, by transudation through the walls of the vessels in which the blood is contained. And this vivifying influence depends upon the corpuscles of the blood. The proof of these statements lies in the following experiments:—If the vessels of a limb of a living animal be tied in such a manner as to cut off the supply of blood from the limb, without affecting it in any other way, all the symptoms of

death will set in. The limb will grow pale and cold, it will lose its sensibility, and volition will no longer have power over it; it will stiffen, and eventually mortify and decompose.

But, if the ligatures be removed before the death stiffening has become thoroughly established and the blood be allowed to flow into the limb, the stiffening speedily ceases, the temperature of the part rises, the sensibility of the skin returns, the will regains power over the muscles, and, in short, the part returns to its normal condition.

If, instead of simply allowing the blood of the animal operated upon to flow again, such blood, deprived of its fibrin by whipping, but containing its corpuscles, be artificially passed through the vessels, it will be found nearly as effectual a restorative as entire blood; while, on the other hand, the serum (which is equivalent to whipped blood without its corpuscles) has no such effect.

It is not necessary that the blood thus artificially injected should be that of the subject of the experiment. Men, or dogs, bled to apparent death, may be at once and effectually revived by filling their veins with blood taken from another man, or dog; an operation which is known by the name of *transfusion.*

Nor is it absolutely necessary for the success of this operation that the blood used in transfusion should belong to an animal of the same species. The blood of a horse will permanently revive an ass, and, speaking generally, the blood of one animal may be replaced without injurious effects by that of another closely-allied species; while that of a very different animal will be more or less injurious, and may even cause immediate death.

20. The *Lymph*, which fills the lymphatic vessels, is, like the blood, an alkaline fluid, consisting of a plasma and corpuscles, and coagulates by the separation of fibrin from the plasma. The lymph differs from the blood in its corpuscles being all of the colourless kind, and in the very small proportion of its solid constituents, which amount to only about 5 per cent. of its weight. Lymph may, in fact, be regarded as blood *minus* its red corpuscles, and diluted with water, so as to be somewhat less

dense than the serum of blood, which contains about 8 per cent. of solid matters.

A quantity of fluid equal to that of the blood is probably poured into the blood, daily, from the lymphatic system. This fluid is in great measure the mere overflow of the blood itself—plasma which has exuded from the capillaries into the tissues, and thus has escaped passing on into the venous current; the rest is due to the absorption of chyle from the alimentary canal.

LESSON IV.

RESPIRATION.

1. THE blood, the general nature and properties of which have been described in the preceding Lesson, is the highly complex product, not of any one organ or constituent of the body, but of all. Many of its features are doubtless given to it by its intrinsic and proper structural elements, the corpuscles; but the general character of the blood is also profoundly affected by the circumstance that every other part of the body takes something from the blood and pours something into it. The blood may be compared to a river, the nature of the contents of which is largely determined by that of the head waters, and by that of the animals which swim in it; but which is also very much affected by the soil over which it flows, by the water-weeds which cover its banks, and by affluents from distant regions; by irrigation works which are supplied from it, and by drain-pipes which flow into it.

2. One of the most remarkable and important of the changes effected in the blood is that which results, in most parts of the body, from its simply passing through capillaries, or, in other words, through vessels the walls of which are thin enough to permit a free exchange between the blood and the fluids which permeate the adjacent tissues (Lesson II. § 1).

Thus, if blood be taken from the artery which supplies a limb, it will be found to have a bright scarlet colour; while blood drawn, at the same time, from the vein of the limb, will be of a purplish hue, so dark that it is commonly called "black blood." And as this contrast is met

with in the contents of the arteries and veins in general (except the pulmonary artery and veins), the scarlet blood is commonly known as *arterial* and the dark blood as *venous*.

This conversion of arterial into venous blood takes place in most parts of the body, while life persists. Thus, if a limb be cut off and scarlet blood be forced into its arteries by a syringe, it will issue from the veins as dark blood.

3. When specimens of venous and of arterial blood are subjected to chemical examination, the differences presented by their solid and fluid constituents are found to be very small and inconstant. But the gaseous contents of the two kinds of blood differ widely in the proportion which the carbonic acid gas bears to the oxygen; there being a smaller quantity of oxygen and a greater quantity of carbonic acid, in venous than in arterial blood.

And it may be experimentally demonstrated that this difference in their gaseous contents is the only essential difference between venous and arterial blood. For if venous blood be shaken up with oxygen, or even with air, it gains oxygen, loses carbonic acid, and takes on the colour and properties of arterial blood. Similarly, if arterial blood be treated with carbonic acid so as to be thoroughly saturated with that gas, it gains carbonic acid, loses oxygen, and acquires the true properties of venous blood; though, for a reason to be mentioned below, the change is not so complete in this case as in the former. The same result is attained, though more slowly, if the blood, in either case, be received into a bladder, and then placed in the carbonic acid, or oxygen gas; the thin moist animal membrane allowing the change to be effected with perfect ease, and offering no serious impediment to the passage of either gas.

4. The physico-chemical processes involved in the exchange of carbonic acid for oxygen, when venous is converted into arterial blood, or the reverse, in the cases mentioned above, are of a somewhat complex nature.

It is known (*a*) that gases, mechanically held by a fluid in a given proportion, tend to diffuse into any atmosphere to which they are exposed until they occupy that atmosphere in corresponding proportions; and (*b*) that gases

separated by a dry porous partition, or simply in contact, diffuse into one another with a rapidity which is inversely proportioned to the square roots of their densities. A knowledge of these physical principles does, in a rough way, lead us to see how the gases contained in the blood may effect an exchange with those in the air, whether the blood be freely exposed, or inclosed in a membrane.

But the application of these principles gives no more than this sort of general insight. For, in the first place, when arterialization takes place through the walls of a bladder, or any other thin animal membrane, the matter is complicated by the circumstance that moisture dissolves carbonic acid far more freely than it will oxygen; hence a wet bladder has a very different action upon carbonic acid from that which it has upon oxygen. A moist bladder, partially filled with oxygen, and suspended in carbonic acid gas, becomes rapidly distended, in consequence of the carbonic acid gas passing into it with much greater rapidity than the oxygen passes out. Secondly, the gases of the blood are not held in a merely mechanical way in it; the oxygen seems to be loosely combined with the red corpuscles (Lesson III. § 16), and there is reason to think that a great part, at least, of the carbonic acid, is chemically connected, in a similarly loose way, with certain saline constituents of the serum. Hence the arterialization of blood in the lungs seems to be a very mixed process, partly physical, and yet, to a certain extent chemical, and consequently very difficult to analyse.

The same may also be said of the change from arterial to venous blood in the tissues. Owing to the peculiar relation of oxygen to the red blood-corpuscles, the process which takes place in the tissues is not a simple interchange by diffusion of the oxygen of the blood for the carbonic acid of the tissues; on the contrary, the oxygen is given up for purposes of oxidation, the demand being determined by the activity of the tissue, while the blood, poor in carbonic acid, takes up, apparently by an independent action, a quantity of that gas from the tissues rich in it.

Hence venous blood is characterized not only by the large amount of carbonic acid present, but also by the

fact that the red corpuscles have given up a good deal of their oxygen for the purposes of oxidation, or, as the chemists would say, have become reduced. This is the reason why arterial blood is not so easily converted into venous blood by exposure to carbonic acid as venous blood into arterial by exposure to oxygen. There is, in the former case, a want of some oxidizable substance to carry off the oxygen from and so to reduce the red corpuscles. When such an oxidizable substance is added (as, for instance, a salt of iron) the blood at once and immediately becomes completely venous.

Practically we may say that the most important difference between venous and arterial blood is not so much the relative quantities of carbonic acid as that the red corpuscles of venous blood have lost a good deal of oxygen, are reduced, and ready at once to take up any oxygen offered to them.

5. Similarly the loss of oxygen by the red corpuscles is the chief reason why the scarlet arterial blood turns of a more purple or claret colour in becoming venous. It has indeed been urged that the red corpuscles are rendered somewhat flatter by oxygen gas, while they are distended by the action of carbonic acid (Lesson III. § 4). Under the former circumstances they may, not improbably, reflect the light more strongly, so as to give a more distinct coloration to the blood; while, under the latter, they may reflect less light, and, in that way, allow the blood to appear darker and duller.

This, however, can only be a small part of the whole matter; for solutions of hæmoglobin or of blood-crystals (Lesson III. § 9), even when perfectly free from actual blood-corpuscles, change in colour from scarlet to purple, according as they gain or lose oxygen. It has already been stated (Lesson III. § 16), that oxygen most probably exists in the blood in loose combination with hæmoglobin. And further, there is evidence to show that a solution of hæmoglobin, when thus loosely combined with oxygen, has a scarlet colour, while a solution of hæmoglobin deprived of oxygen has a purplish hue. Hence arterial blood, in which the hæmoglobin is richly provided with oxygen, would naturally be scarlet, while venous blood, which not only contains an excess of

carbonic acid, but whose hæmoglobin also has lost a great deal of its oxygen, would be purple.

6. Now all the tissues, as we have seen, are continually using up oxygen. Their life in fact is dependent on a continual succession of oxidations. Hence they are greedy of oxygen, while at the same time they are continually producing carbonic acid (and other waste products). Thus, as the blood is flowing through the capillaries of a tissue we have on the one side of the permeable capillary wall the blood with its corpuscles rich in oxygen, and on the other side the tissue in constant want of oxygen, and constantly producing a large quantity of carbonic acid. The result is that the oxygen flies from the red corpuscles through the capillary wall to the tissue, which at once takes it up, while the carbonic acid passes from the tissue where it is in excess through the capillary wall to the blood which, though containing carbonic acid, does not hold so much as the tissue. The blood therefore leaves the tissue poorer in oxygen and richer in carbonic acid than when it came to it; and this change is the change from the arterial to the venous condition.

On the other hand, if we seek for the explanation of the conversion of the dark blood in the veins into the scarlet blood of the arteries, we find, 1st, that the blood remains dark in the right auricle, the right ventricle, and the pulmonary artery; 2nd, that it is scarlet not only in the aorta, but in the left ventricle, the left auricle, and the pulmonary veins.

Obviously, then, the change from venous to arterial takes place in the pulmonary capillaries, for these are the sole channels of communication between the pulmonary arteries and the pulmonary veins.

7. But what are the physical conditions to which the blood is exposed in the pulmonary capillaries?

These vessels are very wide, thin walled, and closely set, so as to form a network with very small meshes, which is contained in the substance of an extremely thin membrane. This membrane is in contact with the air, so that the blood in each capillary of the lung is separated from the air by only a delicate pellicle formed by its own wall and the lung membrane. Hence an exchange very readily takes place between the blood and the air; the latter

gaining moisture and carbonic acid, and losing oxygen (Lesson I. §§ 23, 24).[1]

This is the essential step in respiration. That it really takes place may be demonstrated very readily, by the experiment described in the first Lesson (§ 3), in which air expired was proved to differ from air inspired, by containing more heat, more water, more carbonic acid, and less oxygen ; or, on the other hand, by putting a ligature on the windpipe of a living animal so as to prevent air from passing into, or out of, the lungs, and then examining the contents of the heart and great vessels. The blood on both sides of the heart, and in the pulmonary veins and aorta, will then be found to be as completely venous as in the venæ cavæ and pulmonary artery.

But though the passage of carbonic acid gas and hot watery vapour out of the blood and of oxygen into it is the essence of the respiratory process—and thus a membrane with blood on one side, and air on the other, is all that is absolutely necessary to effect the purification of the blood—yet the accumulation of carbonic acid is so rapid, and the need for oxygen so incessant, in all parts of the human body, that the former could not be cleared away, nor the latter supplied, with adequate rapidity, without the aid of extensive and complicated accessory machinery—the arrangement and working of which must next be carefully studied.

8. The back of the mouth or *pharynx* communicates by two channels with the external air (see Fig. 40). One of these is formed by the nasal passages, which cannot be closed by any muscular apparatus of their own ; the other is presented by the mouth, which can be shut or opened at will.

Immediately behind the tongue, at the lower and front part of the pharynx, is an aperture—the *glottis* (Fig. 19 *Gl*)—capable of being closed by a sort of lid—the *epiglottis*—or by the shutting together of its side boundaries, formed by the so-called *vocal chords*. The glottis

[1] The student must guard himself against the idea that arterial blood contains no carbonic acid, and venous blood no oxygen. In passing through the lungs venous blood loses only a part of its carbonic acid ; and arterial blood, in passing through the tissues, loses only a part of its oxygen. In blood, however venous, there is in health always some oxygen; and in even the brightest arterial blood there is actually more carbonic acid than oxygen.

opens into a chamber with cartilaginous walls — the *larynx;* and leading from the larynx downwards along the front part of the throat, where it may be very readily felt, is the *trachea*, or windpipe (Fig. 19, *Tr*).

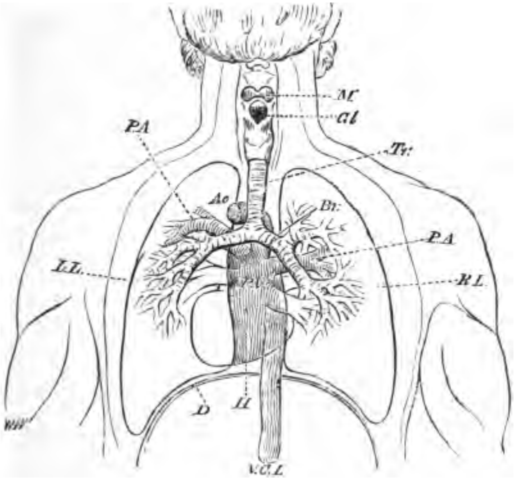

FIG. 19.—BACK VIEW OF THE NECK AND THORAX OF A HUMAN SUBJECT FROM WHICH THE VERTEBRAL COLUMN AND WHOLE POSTERIOR WALL OF THE CHEST ARE SUPPOSED TO BE REMOVED.

M, mouth; *Gl*, glottis; *Tr*, trachea; *L.L*, left lung; *R.L*, right lung; *Br*, bronchus; *P.A*, pulmonary artery; *P.V*, pulmonary veins; *Ao*, aorta; *D*, diaphragm; *H*, heart; *V.C.I*, vena cava inferior.

If the trachea be handled through the skin, it will be found to be firm and resisting. Its walls are, in fact, strengthened by a series of cartilaginous hoops, which hoops are incomplete behind, their ends being united only by muscle and membrane, where the trachea comes into contact with the gullet, or *œsophagus*. The trachea passes into the thorax, and there divides into two branches, a right and a left, which are termed the *bronchi* (Fig. 19, *Br*). Each bronchus enters the lung of its own side,

and then breaks up into a great number of smaller branches, which are called the *bronchial tubes*. As these diminish in size, the cartilages, which are continued all through the bronchi and their large ramifications, become smaller and eventually disappear, so that the walls of the smallest bronchial tubes are entirely muscular or membranous. Thus while the trachea and bronchi are kept permanently open and pervious to air by their cartilages, the smaller bronchial tubes may be almost closed by the contraction of their muscular walls.

The finer bronchial tubes end at length in elongated dilatations, about $\frac{1}{40}$th of an inch in diameter on the average (Fig. 20, A). Each of these dilatations is beset with, or perhaps rather is made up of, little sacs, which open irregularly into the cavity of the dilatation. These sacs are the *air-cells*. The very thin walls (Fig. 20, B) which separate these air-cells are supported by much delicate and highly elastic tissue, and carry the wide and close-set capillaries into which the ultimate ramifications of the pulmonary artery pour its blood (Fig. 20, D). Thus, the blood contained in these capillaries is exposed on both sides to the air—being separated from the air-cell on either hand only by the very delicate pellicle which forms the wall of the capillary, and the lining of the air-sac.

9. Hence no conditions can be more favourable to a ready exchange between the gaseous contents of the blood and those of the air in the air-cells, than the arrangements which obtain in the pulmonary capillaries; and, thus far, the structure of the lung fully enables us to understand how it is that the large quantity of blood poured through the pulmonary circulation becomes exposed in very thin streams, over a large surface, to the air. But the only result of this arrangement would be, that the pulmonary air would very speedily lose all its oxygen, and become completely saturated with carbonic acid, if special provision were not made for its being incessantly renewed.

10. If an adult man, breathing calmly in the sitting position, be watched, the respiratory act will be observed to be repeated thirteen to fifteen times every minute. Each act consists of certain components which succeed one another in a regular rhythmical order. First, the breath is drawn in, or *inspired;* immediately afterwards

it is driven out, or *expired;* and these successive acts of *inspiration* and *expiration* are followed by a brief pause. Thus, just as in the rhythm of the heart the auricular systole, the ventricular systole, and then a pause, follow in

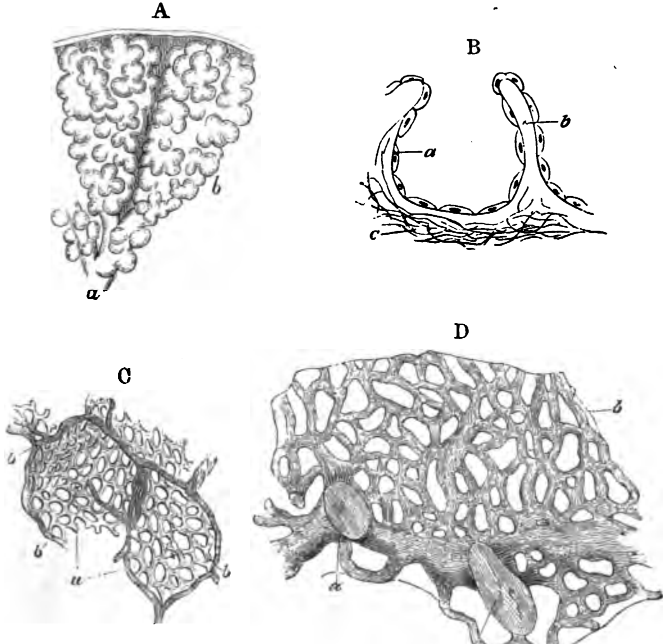

FIG. 20.

A. Two air-cells (*b*) with the ultimate bronchial tube (*a*) which opens into them. (Magnified 20 diameters.)

B. Diagrammatic view of an air-cell of A seen in section: *a*, epithelium; *b*, partition between two adjacent cells, in the thickness of which the capillaries run; *c*, fibres of elastic tissue.

C. Portion of injected lung magnified: *a*, the capillaries spread over the walls of two adjacent air-cells; *b*, small branches of arteries and veins.

D. Portion still more highly magnified.

regular order; so in the chest, the inspiration, the expiration, and then a pause succeed one another. But in the chest, unlike the case of the heart, the pause is generally very short compared with the active movement; indeed, sometimes it hardly exists at all, a new inspiration following immediately upon the close of expiration. At each inspiration of an adult well-grown man about thirty cubic inches of air are inspired; and at each expiration the same, or a slightly smaller, volume (allowing for the increase of temperature of the air so expired) is given out of the body.

11. The expired air differs from the air inspired in the following particulars:—

(*a*) Whatever the temperature of the external air is, that expired is nearly as hot as the blood, or has a temperature between 98° and 100°.

(*b*) However dry the external air may be, that expired is quite, or nearly, saturated with watery vapour.

(*c*) Though ordinary air contains nearly 2,100 parts of oxygen, and 7,900 of nitrogen, with not more than 3 parts of carbonic acid, in 10,000 parts, expired air contains about 470 parts of carbonic acid, and only between 1,500 and 1,600 parts of oxygen; while the quantity of nitrogen suffers little or no change. Speaking roughly, air which has been breathed once has gained five per cent. of carbonic acid, and lost five per cent. of oxygen.

The expired air contains, in addition, a greater or less quantity of animal matter of a highly decomposable character.

(*d*) Very close analysis of the expired air shows, firstly, that the quantity of oxygen which disappears is always slightly in excess of the quantity of carbonic acid supplied; for all the oxygen taken in does not go to form carbonic acid, some of it is employed to unite with hydrogen (forming water), and indeed with other elements; and secondly, that the nitrogen is variable—the expired nitrogen being sometimes slightly in excess of, sometimes slightly less than, that inspired, and sometimes remaining stationary.

12. From three hundred and fifty to four hundred cubic feet of air are thus passed through the lungs of an adult man taking little or no exercise, in the course of twenty-

four hours; and are charged with carbonic acid, and deprived of oxygen, to the extent of nearly five per cent. This amounts to about eighteen cubic feet of the one gas taken in, and of the other given out. Thus, if a man be shut up in a close room, having the form of a cube seven feet in the side, every particle of air in that room will have passed through his lungs in twenty-four hours, and a fourth of the oxygen it contained will be replaced by carbonic acid.

The quantity of carbon eliminated in the twenty-four hours is pretty nearly represented by a piece of pure charcoal weighing eight ounces.

The quantity of water given off from the lungs in the twenty-four hours varies very much, but may be taken on the average as rather less than half a pint, or about nine ounces. It may fall below this amount, or increase to double or treble the quantity.

13. The mechanical arrangements by which the respiratory movements, essential to the removal of the great mass of effete matters, and the importation of the large quantity of oxygen indicated, are effected, may be found in—(*a*) the elasticity of the lungs; (*b*) the mobility of the sides and bottom of the thoracic cavity in which the lungs are contained.

The thorax may be regarded as a completely shut conical box, with the small end turned upwards, the back of the box being formed by the spinal column, the sides by the ribs, the front by the breast-bone, the bottom by the diaphragm, and the top by the root of the neck (Fig. 19).

The two lungs occupy almost all the cavity of this box which is not taken up by the heart. Each is enclosed in its serous membrane, the *pleura*, a double bag (very similar to the pericardium, the chief difference being that the outer bag of each pleura is, over the greater part of its extent, quite firmly adherent to the walls of the chest and the diaphragm (see Fig. 9), while the outer bag of the pericardium is for the most part loose), the inner bag closely covering the lung and the outer forming a lining to the cavity of the chest. So long as the walls of the thorax are entire, the cavity of each pleura is practically obliterated, that layer of the pleura which covers the lung being in close contact with that which lines the wall of the

chest; but if a small opening be made into the pleura, the lung at once shrinks to a comparatively small size, and thus develops a great cavity between the two layers of the pleura. If a pipe be now fitted into the bronchus,

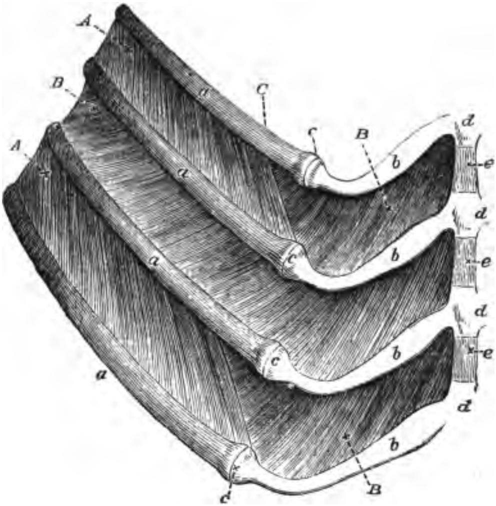

FIG. 21.—VIEW OF FOUR RIBS OF THE DOG WITH THE INTERCOSTAL MUSCLES.

a, the bony rib; *b*, the cartilage; *c*, the junction of bone and cartilage; *d*, unossified, *e*, ossified, portions of the sternum. *A*, external intercostal muscle. *B*, internal intercostal muscle. In the middle interspace, the external intercostal has been removed to show the internal intercostal beneath it.

and air blown through it, the lung is very readily distended to its full size; but, on being left to itself, it collapses, the air being driven out again with some force. The abundant elastic tissues of the walls of the air-cells are, in fact, so disposed as to be greatly stretched when the lungs are full; and, when the cause of the distension

is removed, this elasticity comes into play and drives the greater part of the air out again.

The lungs are kept distended in the dead subject, so long as the walls of the chest are entire, by the pressure of the atmosphere. For though the elastic tissue is all the while pulling, as it were, at the layer of pleura which covers the lung, and attempting to separate it from that which lines the chest, it cannot produce such a separation without developing a vacuum between these two layers. To effect this, the elastic tissue must pull with a force greater than that of the external air (or fifteen pounds to the square inch), an effort far beyond its powers, which do not equal more than one-fourth of a pound on the square inch. But the moment a hole is made in the pleura, the air enters into its cavity, the atmospheric pressure inside the lung is equalized by that outside it, and the elastic tissue, freed from its opponent, exerts its full power on the lung.

14. The lungs are elastic, whether alive or dead. During life the air which they contain may be further affected by the contractility of the muscular walls of the bronchial tubes. If water is poured into the lungs of a recently-killed animal, and a series of electric shocks is then sent through the bronchial tubes, the latter contract, and the water is forced out. Lastly, during life a further source of motion in the bronchial tubes is provided by the *cilia* —minute filaments attached to the epithelium of the tubes, which incessantly vibrate backwards and forwards, and work in such a manner as to sweep liquid and solid matters outwards, or towards the trachea. But these cilia have practically no effect on the movement of the air in the lungs, and the contractions of the muscular walls of the bronchi are probably made use for special purposes only.

15. The ribs are attached to the spine, so as to be freely moveable upon it; but when left to themselves they take a position which is inclined obliquely downwards and forwards.[1] Two sets of muscles, called *intercostals*, pass

[1] I purposely neglect the consideration of the cartilages of the ribs, and some other points, in order not to complicate the question unnecessarily. It may, however, be stated that those fibres of the internal intercostals which are situated between the cartilages act probably like the external, and raise the ribs.

between the successive pairs of ribs on each side. The outer set, called *external intercostals* (Fig. 21, *A*), run from the rib above, obliquely downwards and forwards, to the rib below. The other set, *internal intercostals* (Fig. 21, *B*), cross these in direction, passing from the rib above, downwards and backwards, to the rib below.

The action of these muscles is somewhat puzzling at first, but is readily understood if the fact that *when a muscle contracts, it tends to shorten the distance between its two ends* be borne in mind. Let *a* and *b* in Fig. 22, A, be two parallel bars, moveable by their ends upon the

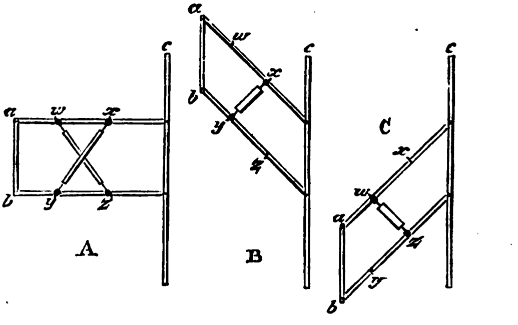

FIG. 22.—DIAGRAM OF MODELS ILLUSTRATING THE ACTION OF THE EXTERNAL AND INTERNAL INTERCOSTAL MUSCLES.

B, inspiratory elevation; C, expiratory depression.

upright *c*, which may be regarded as at the back of the apparatus, then a line directed from *x* to *y* will be inclined downwards and forwards, and one from *w* to *z* will be directed downwards and backwards. Now it is obvious from the figure that the distance between *x* and *y* is shorter in B than in A and much shorter than in C; hence when *x y* is shortened the bars will be pulled up from the position C or A to or towards the position B. Conversely the shortening of *w z* will tend to pull the bars down from the position B or the position A to or towards the position C.

If the simple apparatus just described be made of wood, hooks being placed at the points *x y*, and *w z*; and an elastic band be provided with eyes which can be readily put on to or taken off these hooks; it will be found that the band being so short as to be put on the stretch when hooked on to either *x y*, or *w z*, with the bars in the horizontal position, A, the elasticity of the band, when hooked on to *x* and *y*, will bring them up as shown in B; while, if hooked on to *w* and *z*, it will bring them down as shown in C.

Substitute the contractility of the external and internal intercostal muscles for the shortening of the band, in virtue of its elasticity, and the model will exemplify the action of these muscles; the external intercostals in shortening will tend to raise, and the internal intercostals to depress, the bony ribs.

Such a model, however, does not accurately represent the ribs, with their numerous and peculiar curves, and hence, while all are agreed that the external intercostals raise the ribs, the action of the internal intercostals is not quite so certain.

16. The diaphragm is a great partition situated between the thorax and the abdomen, and always concave to the latter and convex to the former (Fig. 1, *D*). From its middle, which is tendinous, muscular fibres extend downwards and outwards to the ribs, and two, especially strong masses, which are called the *pillars of the diaphragm*, to the spinal column (Fig. 23). When these muscular fibres contract, therefore, they tend to make the diaphragm flatter, and to increase the capacity of the thorax at the expense of that of the abdomen, by pulling down the bottom of the thoracic box (Fig. 24, *A*).

17. Let us now consider what would be the result of the action of the parts of the respiratory apparatus which have been described, if the diaphragm alone should begin to contract at regular intervals.

When it contracts it increases the vertical dimensions of the thoracic cavity, and tends to pull away the lining of the bottom of the thoracic box from that which covers the bases of the lungs; but the air immediately rushing in at the trachea, proportionately increases the distension of the lungs, and prevents the formation of any vacuum

between the two pleuræ of either lung in this region. When the diaphragm ceases to contract, so much of the elasticity of the lungs as was neutralized by the contraction of the diaphragm, comes into play, and the extra air taken in is driven out again. We have, in short, an *Inspiration* and an *Expiration.*

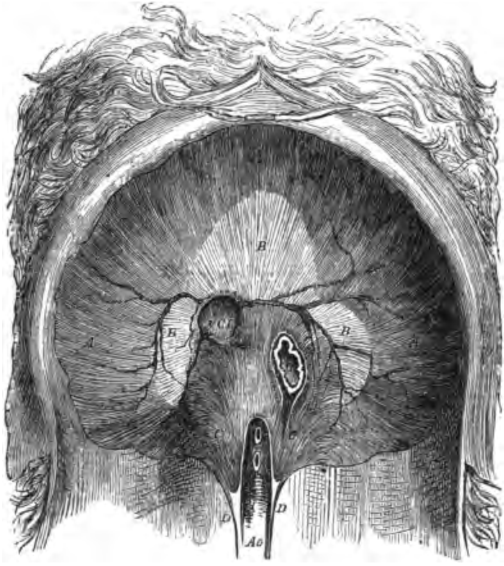

FIG. 23.—THE DIAPHRAGM OF A DOG VIEWED FROM THE LOWER OR ABDOMINAL SIDE.

V.C.I, the vena cava inferior; *O*, the œsophagus; *Ao*, the aorta; the broad white tendinous middle (*B*) is easily distinguished from the radiating muscular fibres (*A*) which pass down to the ribs and into the pillars (*C D*) in front of the vertebræ.

Suppose on the other hand, that, the diaphragm being quiescent, the external intercostal muscles contract. The ribs will be raised from their oblique position, the antero-posterior dimensions of the thoracic cavity will be

increased (for each rib, as it moves from the slanting to the horizontal position, must thrust the sternum outwards), and the lungs will be distended as before to balance the enlargement. If now the external intercostals relax, the action of gravity upon the ribs, the elasticity of the cartilages, and more especially that of the lungs, will alone suffice to bring back the ribs to their previous positions and to drive out the extra air; and this expiratory action may be aided by the contraction of the internal intercostals.

18. Thus it appears that we may have either *diaphragmatic respiration*, or *costal respiration*. As a general rule, however, not only do the two forms of respiration coincide and aid one another—the contraction of the diaphragm taking place at the same time with that of the external intercostals, and its relaxation with their relaxation—but sundry other accessory agencies come into play. Thus, the muscles which connect the ribs with parts of the spine above them, and with the shoulder, may, more or less extensively, assist inspiration, especially certain muscles which pull up and fix the first two ribs and so allow the whole force of each external intercostal muscle to be spent in raising the rib below it; while those which connect the ribs and breast-bone with the pelvis, and form the front and side walls of the abdomen, are powerful aids to expiration. In fact they assist expiration in two ways: first, directly, by pulling down the ribs; and next, indirectly, by pressing the viscera of the abdomen upwards against the under surface of the diaphragm, and so driving the floor of the thorax upwards.

It is for this reason that, whenever a violent expiratory effort is made, the walls of the abdomen are obviously flattened and driven towards the spine, the body being at the same time bent forwards.

In taking a deep inspiration, on the other hand, the walls of the abdomen are relaxed and become convex, the viscera being driven against them by the descent of the diaphragm—the spine is straightened, the head thrown back, and the shoulders outwards, so as to afford the greatest mechanical advantage to all the muscles which can elevate the ribs.

19. It is a remarkable circumstance that the mechanism

of respiration is somewhat different in the two sexes. In men, the diaphragm takes the larger share in the process, the upper ribs moving comparatively little ; in women, the reverse is the case, the respiratory act being more largely the result of the movement of the ribs.

Sighing is a deep and prolonged inspiration. "*Sniffing*" is a more rapid inspiratory act, in which the mouth is kept shut, and the air made to pass through the nose.

Coughing is a violent expiratory act. A deep inspiration being first taken, the glottis is closed and then burst open by the violent compression of the air contained in the lungs by the contraction of the expiratory muscles, the diaphragm being relaxed and the air driven through the mouth. In *sneezing*, on the contrary, the cavity of the mouth being shut off from the pharynx by the approximation of the soft palate and the base of the tongue, the air is forced through the nasal passages.

20. It thus appears that the thorax, the lungs, and the trachea constitute a sort of bellows without a valve, in which the thorax and the lungs represent the body of the bellows, while the trachea is the pipe ; and the effect of the respiratory movements is just the same as that of the approximation and separation of the handles of the bellows, which drive out and draw in the air through the pipe. There is, however, one difference between the bellows and the respiratory apparatus, of great importance in the theory of respiration, though frequently overlooked ; and that is, that the sides of the bellows can be brought close together so as to force out all, or nearly all, the air which they contain ; while the walls of the chest, when approximated as much as possible, still inclose a very considerable cavity (Fig. 24, *B*) ; so that, even after the most violent expiratory effort, a very large quantity of air is left in the lungs.

The amount of this air which cannot be got rid of, and is called *Residual air*, is, on the average, from 75 to 100 cubic inches.

About as much more in addition to this remains in the chest after an ordinary expiration, and is called *Supplemental air*.

In ordinary breathing, 20 to 30 cubic inches of what is conveniently called *Tidal air* pass in and out. It follows

that, after an ordinary inspiration, 100 + 100 + 30 = 230 cubic inches, may be contained in the lungs. By taking the deepest possible inspiration, another 100 cubic inches, called *Complemental air*, may be added.

21. It results from these data that the lungs, after an ordinary inspiration, contain about 230 cubic inches of

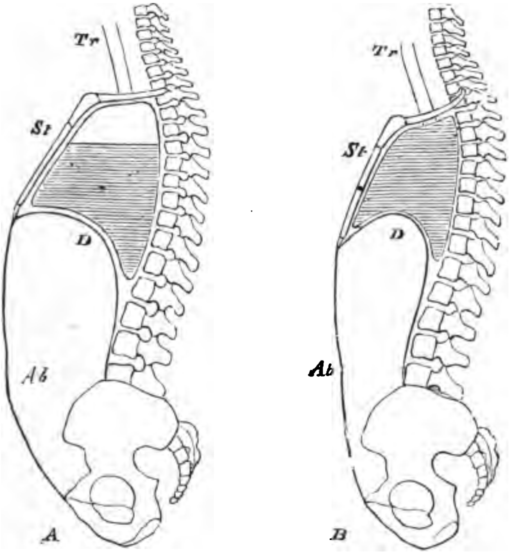

FIG. 24.—DIAGRAMMATIC SECTIONS OF THE BODY IN *A*, inspiration; *B*, expiration. *Tr*, trachea; *St*, sternum; *D*, diaphragm; *Ab*, abdominal walls. The shading roughly indicates the stationary air.

air, and that only about one-seventh to one-eighth of this amount is breathed out and taken in again at the next inspiration. Apart from the circumstance, then, that the fresh air inspired has to fill the cavities of the hinder part of the mouth, and the trachea, and the bronchi, if the lungs were mere bags fixed to the ends of the bronchi, the

inspired air would descend so far only as to occupy that one-fourteenth to one-sixteenth part of each bag which was nearest to the bronchi, whence it would be driven out again at the next expiration. But as the bronchi branch out into a prodigious number of bronchial tubes, the inspired air can only penetrate for a certain distance along these, and can never reach the air-cells at all.

Thus the residual and supplemental air taken together are, under ordinary circumstances, *stationary*—that is to say, the air comprehended under these names merely shifts its outer limit in the bronchial tubes, as the chest dilates and contracts, without leaving the lungs; the *tidal* air, alone, being that which leaves the lungs and is renewed in ordinary respiration.

It is obvious, therefore, that the business of respiration is essentially transacted by the stationary air, which plays the part of a middleman between the two parties—the blood and the fresh tidal air—who desire to exchange their commodities, carbonic acid for oxygen, and oxygen for carbonic acid.

Now there is nothing interposed between the fresh tidal air and the stationary air; they are aëriform fluids, in complete contact and continuity, and hence the exchange between them must take place according to the ordinary laws of gaseous diffusion.

22. Thus, the stationary air in the air-cells gives up oxygen to the blood, and takes carbonic acid from it, though the exact mode in which the change is effected is not thoroughly understood. By this process it becomes loaded with carbonic acid, and deficient in oxygen, though to what precise extent is not known. But there must be a very much greater excess of the one, and deficiency of the other, than is exhibited by inspired air, seeing that the latter acquires its composition by diffusion in the short space of time (four or five seconds) during which it is in contact with the stationary air.

In accordance with these facts, it is found that the air expired during the first half of an expiration contains less carbonic acid than that expired during the second half. Further, when the frequency of respiration is increased without altering the volume of each inspiration, though the percentage of carbonic acid in each inspiration

is diminished, it is not diminished in the same ratio as that in which the number of inspirations increases; and hence more carbonic acid is got rid of in a given time.

Thus, if the number of inspirations per minute is increased from fifteen to thirty, the percentage of carbonic acid evolved in the second case remains more than half of what it was in the first case, and hence the total evolution is greater.

23. Of the various mechanical aids to the respiratory process, the nature and workings of which have now been described, one, the elasticity of the lungs, is of the nature of a dead, constant force. The action of the rest of the apparatus is under the control of the nervous system, and varies from time to time.

As the nasal passages cannot be closed by their own action, air has always free access to the pharynx; but the glottis, or entrance to the windpipe, is completely under the control of the nervous system—the smallest irritation about the mucous membrane in its neighbourhood being conveyed, by its nerves, to that part of the cerebro-spinal axis which is called the *medulla oblongata* (see Lesson XI. § 16). The medulla oblongata, thus stimulated, gives rise, by a process which will be explained hereafter, termed *reflex action*, to the contraction of the muscles which close the glottis, and commonly, at the same time, to a violent contraction of the expiratory muscles, producing a cough (see § 19). The muscular fibres of the smaller bronchial tubes are similarly under the control of the medulla oblongata, sometimes contracting so as to narrow and sometimes relaxing so as to permit the widening of the bronchial passages.

24. These, however, are mere incidental actions. The whole respiratory machinery is worked by a nervous apparatus. From what has been said, it is obvious that there are many analogies between the circulatory and the respiratory apparatus. Each consists, essentially, of a kind of pump which distributes a fluid (aëriform in the one case, liquid in the other) through a series of ramified distributing tubes to a system of cavities (capillaries or air-cells), the volume of the contents of which is greater than that of the tubes. While the heart however is a force-pump, the respiratory machinery represents a suction-pump.

In each, the pump is the cause of the motion of the fluid, though that motion may be regulated, locally, by the contraction or relaxation, of the muscular fibres contained in the walls of the distributing tubes. But, while the rhythmic movement of the heart chiefly depends upon a nervous apparatus placed within itself, that of the respiratory apparatus results mainly from the operation of a nervous centre lodged in the medulla oblongata, which has been called the *respiratory centre.*

The intercostal muscles are supplied by *intercostal* nerves coming from the spinal cord in the region of the back, and the muscular fibres of the diaphragm are supplied by two nerves, one on each side, called the *phrenic* nerves, which starting from certain of the spinal nerves in the neck, dip into the thorax at the root of the neck, and find their way through the thorax by the side of the lungs to the diaphragm, over which they are distributed. Now from the nervous respiratory centre in the medulla oblongata, impulses at repeated intervals descend along the upper part of the spinal cord and, passing out by the phrenic and intercostal nerves respectively, reach the diaphragm and the intercostal muscles. These immediately contract, and thus an inspiration takes place. Thereupon the impulses cease, and are replaced by other impulses, which though starting from the same centre pass, not to the diaphragm and external intercostal muscles, but to other, expiratory, muscles, which they throw into contraction, and thus expiration is brought out. As a general rule the inspiratory impulses are much stronger than the expiratory; indeed, in ordinary quiet breathing expiration is chiefly brought about, as we have seen, by the elasticity of the lungs and chest walls; these need no nervous impulses to set them at work, as soon as the inspiratory impulses cease and the diaphragm and other inspiratory muscles leave off contracting, they come of themselves into action. But, in laboured breathing, very powerful expiratory impulses may leave the medulla and pass to the various muscles whose contractions help to drive the air out of the chest.

The impulses, both inspiratory and expiratory, which are thus started in the medulla, seem to be generated there in a particular way their rapidity and force appearing to

be dependent on the condition of the blood which is circulating in the capillaries of the medulla. When the blood flowing through the medulla becomes more venous, *i.e.* contains less oxygen, the impulses are increased, when it becomes less venous they are diminished. But the character of these respiratory impulses is also determined, in a reflex manner, by impulses passing up to the medulla from the lungs by the pneumogastric nerves, and also by impulses reaching the medulla from other parts of the body along other nerves. Thus, when both pneumogastrics are divided, so that no impulses reach the medulla from the lungs, respiration becomes much slower. And, as is well known, a dash of cold water on the skin makes one draw a deep breath or gasp, owing to the impulses which pass up to the medulla from the part of the skin affected by the cold water.

25. As there are certain secondary phenomena which accompany, and are explained by, the action of the heart, so there are secondary phenomena which are similarly related to the working of the respiratory apparatus. These are—(*a*) the respiratory sounds, and (*b*) the effect of the inspiratory and expiratory movements upon the circulation.

26. The *respiratory sounds* or *murmurs* are audible when the ear is applied to any part of the chest which covers one or other of the lungs. They accompany inspiration and expiration, and very much resemble the sounds produced by breathing through the mouth, when the lips are so applied together as to leave a small interval. Over the bronchi the sounds are louder than over the general surface. It would appear that these sounds are produced by the motion of the air along the air-passages.

27. In consequence of the elasticity of the lungs, a certain force must be expended in distending them, and this force is found experimentally to become greater and greater the more the lung is distended; just as, in stretching a piece of india-rubber, more force is required to stretch it a good deal than is needed to stretch it only a little. Hence, when inspiration takes place, and the lungs are distended with air, the heart and the great vessels in the chest are subjected to a less pressure than are the blood-vessels of the rest of the body.

For the pressure of the air contained in the lungs is exactly the same as that exerted by the atmosphere upon the surface of the body; that is to say, fifteen pounds on the square inch. But a certain amount of this pressure exerted by the air in the lungs is counterbalanced by the elasticity of the distended lungs. Say that in a given condition of inspiration a pound[1] pressure on the square inch is needed to overcome this elasticity, then there will be only fourteen pounds pressure on every square inch of the heart and great vessels. And hence the pressure on the blood in these vessels will be one pound per square inch less than that on the veins and arteries of the rest of the body. If there were no aortic, or pulmonary, valves, and if the composition of the vessels, and the pressure upon the blood in them, were everywhere the same, the result of this excess of pressure on the surface would be to drive all the blood from the arteries and veins of the rest of the body into the heart and great vessels contained in the thorax. And thus the diminution of the pressure upon the thoracic blood cavities produced by inspiration, would, practically, suck the blood from all parts of the body towards the thorax. But the suction thus exerted, while it hastened the flow of blood to the heart in the veins, would equally oppose the flow from the heart to the arteries, and the two effects would balance one another.

As a matter of fact, however, we know—

(1.) That the blood in the great arteries is constantly under a very considerable pressure, exerted by their elastic walls; while that of the veins is under little pressure.

(2.) That the walls of the arteries are strong and resisting, while those of the veins are weak and flabby.

(3.) That the veins have valves opening towards the heart; and that, during the diastole, there is no resistance of any moment to the free passage of blood into the heart: while, on the other hand, the cavity of the arteries is shut off from that of the ventricle, during the diastole, by the closure of the semilunar valves.

Hence it follows that equal pressures applied to the surface of the veins and to that of the arteries must

[1] "A pound" is stated here for simplicity's sake. As a matter of fact the pressure required is less than this.

produce very different effects. In the veins the pressure is something which did not exist before; and partly from the presence of valves, partly from the absence of resistance in the heart, partly from the presence of resistance in the capillaries, it all tends to accelerate the flow of blood *towards* the heart. In the arteries, on the other hand, the pressure is only a fractional addition to that which existed before; so that, during the systole, it only makes a comparatively small addition to the resistance which has to be overcome by the ventricle; and during the diastole, it superadds itself to the elasticity of the arterial walls in driving the blood onwards towards the capillaries, inasmuch as all progress in the opposite direction is stopped by the semilunar valves.

It is, therefore, clear, that the inspiratory movement, on the whole, helps the heart, inasmuch as its general result is to drive the blood the way that the heart propels it.

28. In expiration, the difference between the pressure of the atmosphere on the surface, and that which it exerts on the contents of the thorax through the lungs, becomes less and less in proportion to the completeness of the expiration. Whenever, by the ascent of the diaphragm and the descent of the ribs, the cavity of the thorax is so far diminished that pressure is exerted on the great vessels, the veins, owing to the thinness of their walls, are especially affected, and a check is given to the flow of blood in them, which may become visible as a *venous pulse* in the great vessels of the neck. In its effect on the arterial trunks, expiration, like inspiration, is, on the whole, favourable to the circulation; the increased resistance to the opening of the valves during the ventricular systole being more than balanced by the advantage gained in the addition of the expiratory pressure to the elastic reaction of the arterial walls during the diastole.

When the skull of a living animal is laid open and the brain exposed, the cerebral substance is seen to rise and fall synchronously with the respiratory movements; the rise corresponding with expiration, and being caused by the obstruction thereby offered to the flow of the blood in the veins of the head and neck.

29. The activity of the respiratory process is greatly modified by the circumstances in which the body is placed.

Thus, cold greatly increases the quantity of air which is breathed, the quantity of oxygen absorbed, and of carbonic acid expelled: exercise and the taking of food have a corresponding effect.

In proportion to the weight of the body, the activity of the respiratory process is far greatest in children, and diminishes gradually with age.

The excretion of carbonic acid is greatest during the day, and gradually sinks at night, attaining its minimum about midnight, or a little after.

Indeed it would appear that the rule that the quantity of oxygen taken in by respiration is, approximately, equal to that given out by expiration, only holds good for the total result of twenty-four hours' respiration. Much more oxygen appears to be given out during the day-time (in combination with carbon as carbonic acid) than is absorbed; while, at night, much more oxygen is absorbed than is excreted as carbonic acid during the same period. And it is very probable that the deficiency of oxygen towards the end of the waking hours, which is thus produced, is one cause of the sense of fatigue which comes on at that time. This difference between day and night is, however, not constant, and appears to depend a good deal on the time when food is taken.

The quantity of oxygen which disappears in proportion to the carbonic acid given out, is greatest in carnivorous, least in herbivorous animals—greater in a man living on a flesh diet, than when the same man is feeding on vegetable matters.

30. When a man is strangled, drowned, or choked, or is, in any other way, prevented from inspiring or expiring sufficiently pure atmospheric air, what is called *asphyxia*, comes on. He grows "black in the face;" the veins become turgid; insensibility, not unfrequently accompanied by convulsive movements, sets in, and he is dead in a few minutes.

It is not necessary, however, violently to strangle, or drown, a man, in order to asphyxiate him. As, other things being alike, the rapidity of diffusion between two gaseous mixtures depends on the difference of the proportions in which their constitutents are mixed, it follows that the more nearly the composition of the tidal air

approaches that of the stationary air, the slower will be the diffusion of oxygen inwards, and of carbonic acid outwards, and the more defective in oxygen and charged with carbonic acid will the air in the air-cells become. Hence even with gradual changes in the air breathed, the oxygen in the tidal air being gradually diminished and the carbonic acid in the tidal air being gradually increased, a point will at length be reached when the change effected in the stationary air is too slight to enable it to relieve the pulmonary blood of its carbonic acid, and to supply it with oxygen to the extent required for its arterialisation.

31. Thus, in all cases of asphyxia however produced, the blood passing along the pulmonary veins into the left auricle, instead of being arterial is venous, and becomes more and more venous at each moment. Hence the blood distributed by the left ventricle throughout the body is no longer arterial but venous; all the tissues and organs of the body are supplied with venous instead of arterial blood, and in consequence they all suffer. The respiratory centre in the medulla (see § 24) is perhaps the first to feel it; this gives out impulses which at first manifest themselves in the form of violent laboured inspiratory and expiratory efforts, but eventually end in general convulsions. The brain feels it, and being poisoned by the venous blood ceases to act, so that consciousness disappears and insensibility ensues. The heart and blood vessels feel it and the circulation is disturbed, so that the heart especially on the right side and the whole venous system becomes gorged with blood; hence the blackness in the face. Eventually the nervous system becomes exhausted and all the movements of respiration as well as those of the body at large come to an end; and the heart too, poisoned by the continued venous blood, ceases to beat. Thus death is brought about; all the functions of the body are brought to an end because everywhere there is venous instead of arterial blood.

32. But venous blood is distinguished from arterial by two features, by having less oxygen and more carbonic acid. Hence, in this asphyxiating process, two influences of a distinct nature are co-operating; one is the *deprivation of oxygen*, the other is the *excessive accumulation of carbonic acid* in the blood. Oxygen starvation and carbonic acid

poisoning, each of which is injurious in itself, are at work together.

The effects of oxygen starvation may be studied separately, by placing a small animal under the receiver of an air-pump and exhausting the air; or by replacing the air by a stream of hydrogen or nitrogen gas. In these cases no accumulation of carbonic acid is permitted, but, on the other hand, the supply of oxygen soon becomes insufficient, and the animal quickly dies with all the symptoms of asphyxia. And if the experiment be made in another way, by placing a small mammal, or bird, in air from which the carbonic acid is removed as soon as it is formed, the animal will nevertheless die asphyxiated as soon as the amount of oxygen is reduced to 10 per cent. or thereabouts.

The directly poisonous effect of carbonic acid, on the other hand, has been very much exaggerated. A very large quantity of pure carbonic acid (10 to 15 or 20 per cent.) may be contained in air, without producing any very serious immediate effect, if the quantity of oxygen be simultaneously increased.

Moreover such symptoms as do occur when the carbonic acid in the air breathed is increased without any corresponding decrease in the oxygen, are not exactly those of asphyxia but are said to resemble rather those of narcotic poisoning. So that the chief cause of asphyxia in strangling, drowning, or choking, or however produced, is the diminution of the oxygen in the air of the lungs and consequently a diminution of the oxygen in the blood.

33. And that it is the lack of oxygen which is the important thing is further shown by the asphyxiating effects of certain poisonous gases. Thus sulphuretted hydrogen, so well known by its offensive smell, has long had the repute of being a positive poison. But its evil effects appear to arise chiefly, if not wholly, from the circumstance that its hydrogen combines with the oxygen carried by the blood-corpuscles, and thus gives rise, indirectly, to a form of oxygen starvation.

Carbonic oxide gas has a much more serious effect, as it turns out the oxygen from the blood-corpuscles, and forms a combination of its own with the hæmoglobin. The compound thus formed is only very gradually decom-

posed by fresh oxygen, so that if any large proportion of the blood-corpuscles be thus rendered useless, the animal dies before restoration can be effected. Badly made common coal gas sometimes contains 20 to 30 per cent. of carbonic oxide; and, under these circumstances, a leakage of the pipes in a house may be extremely perilous to life.

34. The first stages of asphyxia, when the breathing is simply hurried or violent, before consciousness is lost and before convulsions set in, is often spoken of as *dyspnœa*, or laboured breathing. And dyspnœa begins to show itself as soon as ever there is any serious diminution of the oxygen in the tidal air. A very slight reduction will hardly effect the breathing at all or only make it rather quicker and deeper, but when the proportion of oxygen in the tidal air is largely diminished, brought down for instance to 10 per cent., the case becomes serious. And it makes no difference whether this condition of the tidal air is brought about by shutting out fresh air, or by augmenting the number of persons who are consuming the same air, or by suffering combustion, in any shape, to carry off oxygen from the air.

But in the case of breathing the same air over and over again the deprivation of oxygen, and the accumulation of carbonic acid, cause injury, long before the asphyxiating point is reached. Under these circumstances uneasiness and headache arise when less than 1 per cent. of the oxygen of the air is replaced by other matters; the symptoms in this case however are due not so much to the diminution of oxygen or the increase of carbonic acid, as to the poisonous effects of the various organic matters present in expired air which, though existing in minute quantities, have a powerfully deleterious action. It need hardly be added that the persistent breathing of such air tends to lower all kinds of vital energy, and predisposes to disease.

Hence the necessity of sufficient air and of ventilation for every human being. To be supplied with respiratory air in a fair state of purity, every man ought to have at least 800 cubic feet of space[1] to himself, and that space ought to be freely accessible, by direct or indirect channels, to the atmosphere.

[1] A cubical room nine feet high, wide and long, contains only 729 cubic feet of air.

LESSON V.

THE SOURCES OF LOSS AND OF GAIN TO THE BLOOD.

1. THE blood which has been aërated, or arterialised, by the process described in the preceding Lesson, is carried from the lungs by the pulmonary veins to the left auricle, and is then forced by the auricle into the ventricle, and by the ventricle into the aorta. As that great vessel traverses the thorax, it gives off several large arteries, by means of which blood is distributed to the head, the arms, and the walls of the body. Passing through the diaphragm (Fig. 23), the aortic trunk enters the cavity of the abdomen, and becomes what is called the *abdominal aorta*, from which vessels are given off to the viscera of the abdomen. Finally, the main stream of blood flows into the *iliac* arteries, whence the viscera of the pelvis and the legs are supplied.

Having in the various parts of the body traversed the ultimate ramifications of the arteries, the blood, as we have seen, enters the capillaries. Here the products of the waste of the tissues constantly pour into it; and, as the blood is everywhere full of corpuscles, which, like all other living things, decay and die, the products of their decomposition also tend to accumulate in it, but these are insignificant compared to those coming from the great mass of the tissues. It follows that, if the blood is to be kept pure, the waste matters thus incessantly poured into, or generated in it, must be as constantly got rid of, or excreted.

2. Three distinct sets of organs are especially charged with this office of continually excreting waste matters from the blood. They are the *lungs*, the *kidneys*, and

the *skin* (see Lesson I. § 23). These three great organs may therefore be regarded as so many drains from the blood—as so many channels by which it is constantly losing substance.

On the other hand, the blood, as it passes through the capillaries, is constantly giving up material by exudation through the capillary walls into the surrounding tissues, in order to supply them with nourishment, and thus in this way also is constantly losing matter.

The material which the blood loses by giving it up to the tissues consists of complex organic bodies, such as proteids, fats, carbohydrates, and various substances manufactured out of these, of certain salts, of a large quantity of water, and lastly of oxygen.

The material which the blood loses by giving it up to the skin, lungs and kidneys, passes away from these organs as water, as carbonic acid, as peculiar organic substances of which one, called *urea*, is much more abundant than the others, and as certain inorganic salts. Speaking generally we may say that these organs together excrete from the blood, water, carbonic acid, urea and salts.

Another kind of loss takes place from the surface of the body generally, and from the interior of the air-passages. Heat is constantly being given off from the former by radiation, evaporation, and conduction: from the latter, chiefly by evaporation; and the loss of heat in each case is borne by the blood passing through the skin and air-passages respectively. Besides this a certain quantity of heat is lost by the urine and fæces which are always warm when they leave the body.

3. On the side of gain we have, in the first place, the various substances which are the products of the activity of the several tissues, muscles, brain, glands, &c., and which pass from the tissues into the blood. We may speak of these as waste products, and one of them which is produced by all the tissues, namely carbonic acid, is emphatically a waste product and is got rid of as soon as possible. But some of the substances which are returned to the blood from the tissues are not wholly useless matters to be thrown off as rapidly as possible; they are capable of being used up again by some tissue or other. Thus, as

we shall see, the liver, at certain times at all events, returns to the blood a certain quantity of sugar which is made use of in other parts of the body, and similarly the spleen, while it takes up certain substances from the blood, gives back to the blood certain other substances which we can hardly speak of as waste matters in the sense of being useless material fit only to be at once thrown away.

In the second place, the blood is continually receiving from the alimentary canal the materials arising from the food which has been digested there. As we shall see, some of this material passes directly from the cavity of the alimentary canal into the blood, but some of it goes in a more roundabout way through what are called the lacteals or lymphatics. On its way to the blood this latter is joined by material which, escaping from the blood and not used by the tissues, or passing from the tissues directly into the lymphatics, is carried back to the blood by the thoracic duct (see Less. II. § 5).

In the third place, the blood is continually gaining oxygen from the air through the lungs.

Then again the blood while it loses heat by the skin and lungs, gains heat from the tissues. As we have already seen (Less. I. § 24) oxidation is continually going on in various parts of the body, and by this oxidation heat is continually being set free. Some of this oxidation may take place in the blood itself; we do not know exactly how much, but probably very little. The greater part of the heat is generated in the tissues, in the muscles and elsewhere, and is given up by the tissues to the blood. So that we may say that the blood gains heat from the tissues.

4. These several gains and losses are for the most part going on constantly but are greater at one time than at another. Thus the gain to the blood from the alimentary canal is much greater some time after a meal than just before the next meal, though unless the meals be very far apart indeed, the whole of the material of one meal has not passed into the blood before the next meal is begun. Again, though the muscles, even when completely at rest, are taking up oxygen and nutritive material, and giving out carbonic acid and other waste products, they give out and take in much more when they are at work. So also certain "secreting glands" as they are called, which we

shall study presently, such as the salivary glands, have periods of repose; it is at certain times only, as when food has been taken, that they pour out any appreciable quantity of fluid. Hence though they are probably taking up material from the blood and storing it up in their substance even when they appear at rest, they take up much more and so become much more distinctly means of loss to the blood, when they are actively pouring out their secretions. In the case of the liver the loss to the blood is more constant, since the secretion of bile as we shall see is continually going on, though greater at certain times than at others; and the materials for the bile have to be provided by the blood. Some of the constituents of the bile, however, pass back from the intestines into the blood; and so far the loss to the blood by the liver is temporary only.

Of all the gains to the blood perhaps the most constant is that of oxygen, and of all the losses perhaps the most constant is that of carbonic acid; but even these vary a good deal at different times or under different circumstances.

Broadly speaking then the blood gains oxygen from the lungs, complex organic food materials from the alimentary canal, and various substances which we may speak of as waste substances from the several tissues; and it loses on the one hand material which we may speak of as constructive material to the several tissues, and on the other hand material which passes away by the skin, lungs, and kidney, as water, carbonic acid, urea, and saline bodies.

And while it is continually receiving heat from the several tissues, it is also continually losing heat by the skin, lungs, and other free surfaces of the body.

5. The sources of loss and gain to the blood may be conveniently arranged in the following tabular form:—

SOURCES OF LOSS OR GAIN TO THE BLOOD.[1]

A. SOURCES OF GAIN :—

I. *Gain of Matter.*

1. The lungs : oxygen (fairly constant).
2. The alimentary canal : food (variable).
3. The tissues : products of their activity, waste matters (always going on but varying according to the activity of the several tissues).
4. The lymphatics : lymph (always going on but varying according to the activity of the several tissues).[2]

II. *Gain of Heat.*

1. The tissues generally, especially the more active ones, such as the muscles.
2. The blood itself, probably to a small extent.

B. SOURCES OF LOSS :—

I. *Loss of Matter.*

1. The lungs : carbonic acid and water (fairly constant).
2. The kidneys : urea, water, salines (fairly constant).
3. The skin : water, salines (fairly constant).
4. The tissues : constructive material (variable especially in the case of those tissues whose activity is intermittent, such as the muscles, many secreting glands, &c.).

II. *Loss of Heat.*

1. The skin.
2. The lungs.
3. The excretions by the kidney and the alimentary canal.

[1] The learner must be careful not to confound the losses and gains of the *blood* with the losses and gains of the *body* as a whole. The two differ in much the same way as the internal commerce of a country differs from its export and import trade.

[2] The gain from those lymphatics which are called lacteals, since it comes from the alimentary canal, varies much more.

6. In the preceding Lesson I have described the operation by which the lungs withdraw from the blood much carbonic acid and water, and supply oxygen to the blood; I now proceed to the second source of continual loss, the KIDNEYS.

Of these organs, there are two, placed at the back of the abdominal cavity, one on each side of the lumbar region of the spine. Each, though somewhat larger than the kidney of a sheep, has a similar shape. The depressed, or concave, side of the kidney is turned inwards, or towards the spine; and its convex side is directed outwards (Fig. 25). From the middle of the concave side (called the *hilus*) of each kidney, a long tube with a small bore, the *Ureter* (*Ur*), proceeds to the bladder (*Bl*).

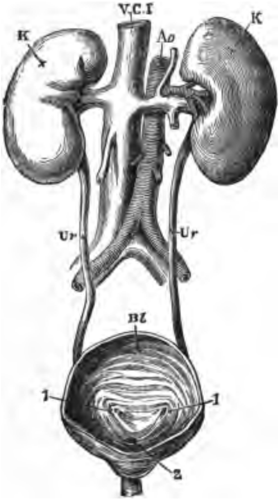

FIG. 25.

The kidneys (*K*); ureters (*Ur*); with the aorta (*Ao*), and vena cava inferior (*V.C.I.*): and the renal arteries and veins. *Bl*, is the bladder, the top of which is cut off so as to show the openings of the ureters (1, 1) and that of the urethra (2).

The latter, situated in the pelvis, is an oval bag, the walls of which contain abundant unstriped muscular fibre, while it is lined, internally, by mucous membrane, and coated externally by a layer of the peritoneum, or double bag of serous membrane which has exactly the same relations to the cavity of abdomen and the viscera contained in them as the pleuræ have to the thoracic cavity and the lungs. The ureters open side by side, but at some little distance from one another, on the posterior and inferior wall of the bladder (Fig. 25, 1, 1). In front of them is a single aperture which leads into the canal called the *Urethra* (Fig. 25, 2), by which the cavity of the bladder is placed in communication with the exterior of the body. The openings of the ureters enter the walls of the bladder obliquely, so that it is much more easy for the fluid to pass from the ureters into the bladder than for it to get the other way, from the bladder into the ureters.

Mechanically speaking, there is little obstacle to the free flow of fluid from the ureters into the bladder, and from the bladder into the urethra, and so outwards; but certain muscular fibres arranged circularly around the part called the "neck" of the bladder, where it joins the urethra, constitute what is termed a *sphincter*, and are usually, during life, in a state of contraction, so as to close the exit of the bladder, while the other muscular fibres of the organ are relaxed.

It is only at intervals that this state of matters is reversed; and the walls of the bladder contracting, while its sphincter relaxes, its contents, the *urine*, are discharged. But, though the expulsion of the secretion of the kidneys from the body is thus intermittent, the excretion itself is constant, and the urinary fluid flows, drop by drop, from the opening of the ureters into the bladder. Here it accumulates, until its quantity is sufficient to give rise to the uneasy sensations which compel its expulsion.

7. The renal excretion has naturally an acid reaction, and consists chiefly of *urea* with a small quantity of *uric acid*, sundry other animal products of less importance, including certain colouring matters, and saline and gaseous substances, all held in solution by a large quantity of water.

The quantity and composition of the urine vary greatly according to the time of day; the temperature and moisture of the air; the fasting or replete condition of the alimentary canal; and the nature of the food.

Urea and uric acid are both composed of the elements carbon, hydrogen, oxygen, and nitrogen; but the urea is by far the more soluble in water, and greatly exceeds the uric acid in quantity.

An average healthy man excretes by the kidneys about fifty ounces, or 24 000 grains of water a day. In this are dissolved 500 grains of urea, but not more than 10 to 12 grains of uric acid.

The amount of other animal matters, and of saline substances, varies from one-third as much to nearly the same amount as the urea. The saline matters consist chiefly of common salt, phosphates and sulphates of potash, soda, lime, and magnesia. The gas which is dissolved in the urine consists chiefly of carbonic acid, with a very small quantity of nitrogen and still less of oxygen.

The average specific gravity does not differ very widely from that of blood serum, being 1·020.

8. The excretion of nitrogenous waste and water, with a little carbonic acid, by the kidneys, is thus strictly comparable to that of carbonic acid and water, by the lungs, in the air-cells of which carbonic acid and watery vapours are incessantly accumulating, to be periodically expelled by the act of expiration. But the operation of the renal apparatus differs from that of the respiratory organs in the far longer intervals between the expulsory acts; and still more in the circumstance that, while the substance which the lungs take into the body is as important as those which they give out, the kidneys take in nothing.

9. We have reason to think that many of the constituents of the urine are present in the blood. These appear in the urine dissolved in a large quantity of water, whereas many other substances also present in the blood do not, in a state of health, make their way into the urine. This suggests the idea that the kidney is a peculiar and delicate kind of filter which allows certain substances together with a large quantity of water to pass through it, but refuses to allow other substances to pass through. And when we come to study the minute structure of the

kidney, to which we must now turn, we find much to support this idea.

When a longitudinal section of a kidney is made (Fig. 26), the upper end of the ureter (*U*) seems to widen out into a basin-like cavity (*P*), which is called the *pelvis* of the kidney. Into this, sundry conical elevations, called the *pyramids* (*Py*) project; and their summits present multitudes of minute openings—the final terminations of the

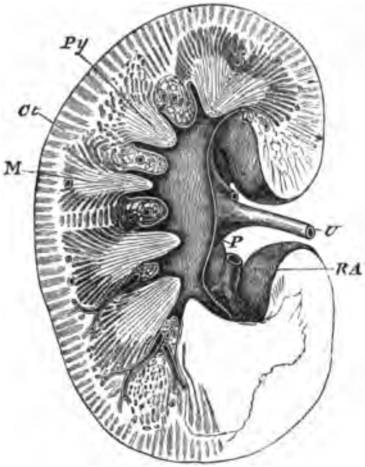

FIG. 26.—LONGITUDINAL SECTION OF THE HUMAN KIDNEY.
Ct, the cortical substance; *M*, the medullary substance; *P*, the pelvis of the kidney; *U*, the ureter; *RA*, the renal artery.

tubuli, of which the thickness of the kidney is chiefly made up. If the tubules be traced from their openings towards the outer surface, they are found, at first, to lie parallel with one another in bundles, which radiate towards the surface, and subdivide as they go; but at length they spread about irregularly, and become coiled and interlaced. From this circumstance, the middle, or *medullary*, part (*medulla*, marrow) of the kidney looks different from the

superficial, or *cortical*, part (*cortex*, bark); but, in addition, the cortical part is more abundantly supplied with vessels than the medullary, and hence has a darker aspect. Each tubule after a very devious course ultimately terminates in a dilatation (Fig. 28) called a *Malpighian capsule*. Into the summit of each capsule, a small vessel (Figs. 28 and 29, *v.a*), one of the ultimate branches of the *renal artery*, which reaches the kidney at the concave side, with the

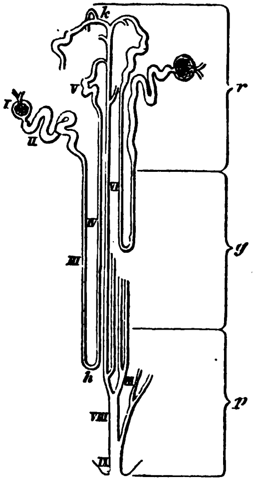

FIG. 27.—DIAGRAMMATIC VIEW OF THE COURSE OF THE TUBULES IN THE KIDNEY.

r, cortical portion answering to *Ct* in Fig. 26, *k* being close to the surface of the kidneys; *g*, *p*, medullary portion, *p* reaching to the summit of the pyramid.
IX, opening of tubule on the pyramid; *VIII*, *VII*, *VI*, the straight portion of the tubules; *V*—*II*, the twisted portion of the tubules; *I*, the Malpighian capsule.

ureters, and divides into branches which pass in between the pyramids (Fig. 26, *RA*), enters (driving the thin wall of the capsule before it), and immediately breaks up into

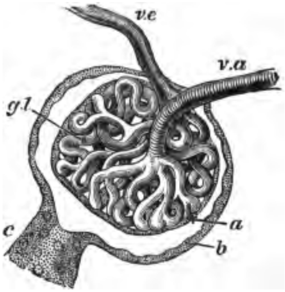

FIG. 28.—A MALPIGHIAN CAPSULE (HIGHLY MAGNIFIED).

va, small branch of renal artery entering the capsule, breaking up into the glomerulus, *g.l*, and finally joining again to form the vein, *v.e*.
c, the tubule; *a*, the epithelium over the glomerulus; *b*, the epithelium lining the capsule.

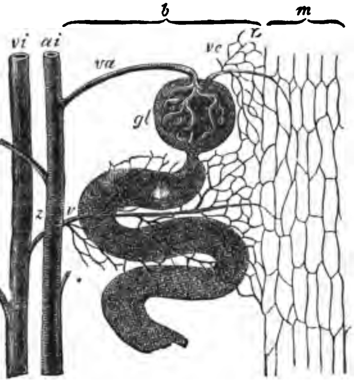

FIG. 29.—CIRCULATION IN THE KIDNEY.

ai, small branch of renal artery giving off the branch *va*, which enters glomerulus, issues as *ve*, and then breaks up into capillaries, which after surrounding the tubule find their way by *v* into *vi*, branch of the renal vein; *m*, capillaries around tubules in parts of the cortical substance where there are no glomeruli.

a bunch of looped capillaries, called a *glomerulus* (Fig. 28, *g.l*), which nearly fills the cavity of the capsule The blood is carried away from this *glomerulus* by a small vein or vessel (*v.e*), which does not, at once, join with other veins into a larger venous trunk, but opens into the network of capillaries (Fig. 29) which surrounds the tubule, thus repeating the portal circulation on a small scale.

The tubule has an epithelial lining (Fig. 28, *c*, and Fig. 30, *a*), continuous with that of the pelvis of the kidney and the urinary passages generally. The epithelium is thick and plain enough in the tubule, but it becomes very delicate in the capsule and on the glomerulus (Fig. 28, *a. b*).

10. It is obvious from this description, that the surface of the glomerulus is, practically, free, or in direct communication with the exterior by means of the cavity of the tubule; and further, that, in each vessel of the glomerulus, a thin stream of blood constantly flows, only separated from the cavity of the tubule by the capillary wall and the very delicate membrane covering the glomerulus. The Malpighian capsule may, in fact, be regarded as a funnel, and the membranous walls of the glomerulus as a piece of very delicate but peculiar filtering-paper, into which the blood is poured.

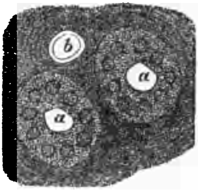

FIG. 30.—TRANSVERSE SECTION OF TWO TUBULES.
a.a, canals of tubules surrounded by their epithelium.
b, a blood-vessel cut across.

11. And indeed we have reason to think that a great deal of the water of urine together with certain of the constituents is thus as it were filtered by the Malpighian capsules. But it must be remembered that the process is after all very different from actual filtering through blotting paper; for blotting paper will let everything pass through that is really dissolved, whereas the glomerulus, while letting some things through, will refuse to admit others even though completely dissolved.

Speaking of the process, with this caution, as one of filtration, it is obvious that the more full the glomerulus is

of blood the more rapid will be the escape of urine. Hence we find that when blood flows freely to the kidney the urine is secreted freely, but that when the blood supply to the kidney is scanty the urine also is scanty. When certain nerves going to the kidney are cut, the ramifications of the renal artery dilate, much blood goes into the kidney and the flow of urine is copious. If the same nerves be irritated, the arterial tubes are narrowed or constricted, less blood goes to the kidney, and the flow of urine is scanty or may be stopped altogether.

And this explains, in part at all events, how it is that the activity of the kidney is influenced by the state of the skin. The quantity of blood in the body, being about the same at all times, if a large quantity goes to the skin, as in warm weather and especially when the skin is active and perspiring, less will go to the kidney, and the secretion of urine will be small. On the other hand, if the blood be largely cut off from the skin, as in cold weather, more blood will be thrown upon the kidney and more urine will be secreted. Thus the skin and the kidneys play into each other's hands in their efforts to get rid of the superfluous water of the body.

12. But the whole of the urine is thus not secreted, through a sort of filtering process, by the Malpighian capsules. The tubules are lined, as has been stated, by epithelium cells, and these cells, in certain parts of the tubule, especially where these are coiled, are what is called *secreting* cells. That is to say they have the power, by some means which we do not at present fully understand, to take up from the blood, which is flowing in the capillaries wound round the tubules, or rather from the plasma which exudes from those capillaries and bathes the bases of the cells, certain substances, and to pour these substances, in some cases greatly changed, in some cases hardly or not at all changed, into the cavity of the tubule. As has been said, even the blood which escapes from the glomerulus and has therefore parted with some of the substances which go to form the urine, is carried to the capillary network wrapped round the tubules, and is there exposed to the further action of the epithelium cells which line those tubules, the plasma which exudes from the capillaries acting as a middle man between the

blood inside the capillary walls and the substance of the cells themselves.

And we have evidence that many of the most important constituents of the urine, such as urea, uric acid and others, are thus secreted by the epithelium cells of the tubules, and not simply filtered off by the Malpighian capsules.

The formation of urine is therefore a double process. A great deal of the water, with probably some of the more soluble inorganic salts, pass by the glomeruli, but the urea, the colouring matters and a great many other of the constituents, are thrown into the cavities of the tubules by a peculiar action of the epithelium cells, some of those substances being actually manufactured by the cell and not existing as such in the blood.

13. That the *skin* is a source of continual loss to the blood may be proved in various ways. If the whole body of a man, or one of his limbs, be enclosed in a caoutchouc bag, full of air, it will be found that this air undergoes changes which are similar in kind to those which take place in the air which is inspired into the lungs. That is to say, the air loses oxygen and gains carbonic acid; it also receives a great quantity of watery vapour, which condenses upon the sides of the bag, and may be drawn off by a properly disposed pipe.

Under ordinary circumstances no liquid water appears upon the surface of the integument, and the whole process receives the name of the *insensible perspiration*. But, when violent exercise is taken, or under some kinds of mental emotion, or when the body is exposed to a hot and moist atmosphere, the perspiration becomes *sensible;* that is, appears in the form of scattered drops upon the surface.

14. The quantity of *sweat*, or sensible perspiration, and also the total amount of both sensible and insensible perspiration, vary immensely, according to the temperature and other conditions of the air, and according to the state of the blood and of the nervous system. It is estimated that, as a general rule, the quantity of water excreted by the skin is about double that given out by the lungs in the same time. The quantity of carbonic acid is not above $\frac{1}{30}$th or $\frac{1}{40}$th of that excreted by the lungs; and it is not

certain that in health any *appreciable* quantity of urea is given off.

In its normal state the sweat, as poured out from the proper sweat-glands, is alkaline; but ordinarily, as it collects upon the skin it is mixed with the fatty secretion of the *sebaceous glands*, and then is frequently acid. In addition it contains scales of the external layers of the epidermis, which are constantly being shed.

15. In analysing the process by which the perspiration is eliminated from the body, it must be recollected, in the first place, that the skin, even if there were no glandular structures connected with it, would be in the position of a moderately thick, permeable membrane, interposed between a hot fluid, the blood, and the atmosphere. Even in hot climates the air is, usually, far from being completely saturated with watery vapour, and in temperate climates it ceases to be so saturated the moment it comes into contact with the skin, the temperature of which is, ordinarily, twenty or thirty degrees above its own.

A bladder exhibits no sensible pores; but if a bladder be filled with water and suspended in the air, the water will gradually ooze through the walls of the bladder, and disappear by evaporation. Now, in its relation to the blood, the skin is such a bladder full of hot fluid.

Thus, perspiration, to a certain amount, must always be going on through the substance of the integument, but probably not to any great extent; though what the amount of this perspiration may be cannot be accurately ascertained, because a second and very important source of the perspiration is to be found in what are called the *sweat-glands*.

16. All over the body the integument presents minute apertures, the ends of channels excavated in the epidermis or scarf-skin, and each continuing the direction of a minute tube, usually about $\frac{1}{300}$th of an inch in diameter, and a quarter of an inch long, which is imbedded in the dermis. Each tube is lined with an epithelium continuous with the epidermis (Fig. 32, *e*). The tube sometimes divides, but, whether single or branched, its inner end or ends are blind, and coiled up into a sort of knot, interlaced with a meshwork of capillaries (Fig. 31, A*g*, and Fig. 33).

The blood in these capillaries is therefore separated from the cavity of the sweat-gland only by the thin walls of the capillaries, that of the glandular tube, and its epithelium, which, taken together, constitute but a very thin pellicle; and the arrangement, though different in detail, is similar in principle to that which obtains in the kidney. In the latter, the vessel makes a coil within the Malpighian capsule, which ends a tubule. Here the perspiratory tubule coils about, and among, the vessels. In both cases the same result is arrived at—namely, the

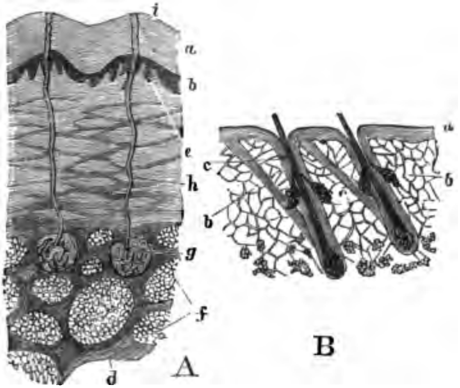

FIG. 31.

A. Section of the skin showing the sweat-glands. *a*, the epidermis; *b*, its deeper layer, the *rete Malpighii*; *e*,*d*, the dermis or true skin; *f*, fat cells; *g*, the coiled end of a sweat-gland; *h*, its duct; *i*, its opening on the surface of the epidermis.

B. Section of the skin showing the roots of the hairs and the sebaceous glands. *b*, muscle of *c*, the hair sheath, on the left hand.

exposure of the blood to a large, relatively free, surface, on to which certain of its contents transude. In the sweat-gland however there is no filtering apparatus like the Malpighian corpuscle of the kidney, and the whole of the sweat appears to be secreted into the interior of the tube by the action of the epithelium cells which line it.

The number of these glands varies in different parts of

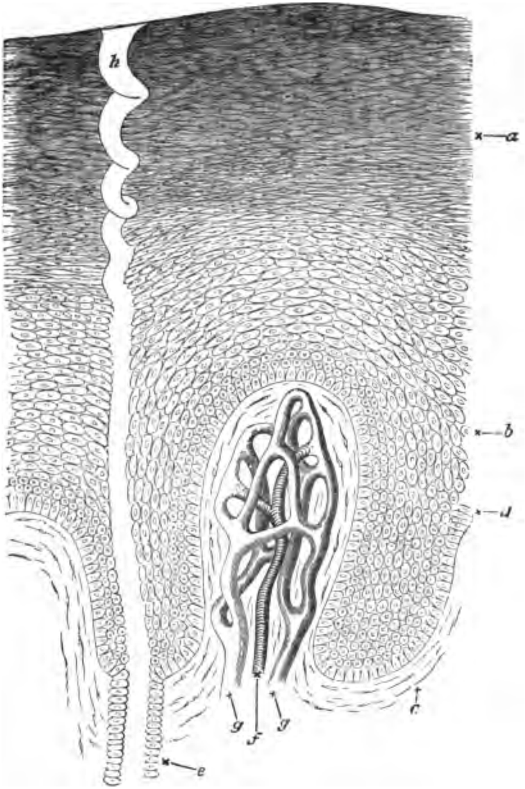

FIG. 32.

Portion of Fig. 31 A, more highly magnified—somewhat diagrammatic. *a*, horny epidermis ; *b*, softer layer, *rete Malpighii* ; *c*, dermis ; *d*, lowermost vertical layer of epidermic cells ; *e*, cells lining the sweat duct continuous with epidermic cells ; *h*, corkscrew canal of sweat duct. To the right of the sweat duct the dermis is raised into a papilla, in which the small artery, *f*, breaks up into capillaries, ultimately forming the veins, *g*.

the body. They are fewest in the back and neck, where their number is not much more than 400 to a square inch. They are more numerous on the skin of the palm and sole, where their apertures follow the ridges visible on the skin, and amount to between two and three thousand on the square inch. At a rough estimate, the whole integument probably possesses not fewer than from two millions and a quarter to two millions and a half of these tubules, which therefore must possess a very great aggregate secreting power.

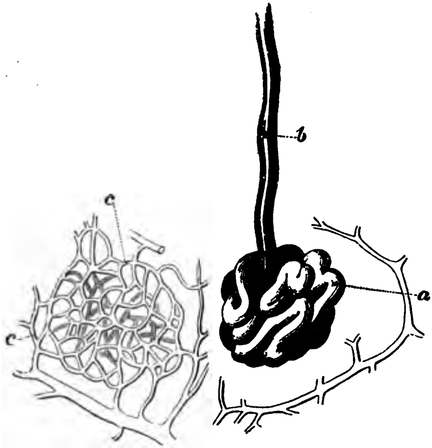

FIG. 33.

Coiled end of a sweat-gland (Fig. 31, *g*), epithelium not shown. *a*, the coil; *b*, the duct; *c*, network of capillaries, inside which the duct gland lies.

17. The sweat-glands are greatly under the influence of the nervous system. This is proved, not merely by the well-known effects of mental emotion in sometimes suppressing the perspiration and sometimes causing it to be poured forth in immense abundance, but has been made a matter of direct experiment. There are some animals, such as the horse, which perspire very freely. If the

sympathetic nerve of one side, in the neck of a horse, be cut, the same side of the head becomes injected with blood, and its temperature rises (see Lesson II. § 24); and, simultaneously, sweat is poured out abundantly over the whole surface thus affected. On irritating that end of the cut nerve which is in connection with the vessels, the muscular walls of the latter, to which the nerve is distributed, contract, the congestion ceases, and with it the perspiration.

On the other hand, experiments have been made on other nerves in other animals in which it is seen that section of the nerve stops perspiration, while stimulation of it causes perspiration, and that independently of any changes in the condition of the blood-vessels. Such nerves may be called 'sweat-nerves' inasmuch as stimulation of them directly excites perspiration.

18. The amount of matter which may be lost by perspiration, under certain circumstances, is very remarkable. Heat and severe labour, combined, may reduce the weight of a man two or three pounds in an hour, by means of the cutaneous perspiration alone; and, as there is some reason to believe that the quantity of solid matter carried off from the blood does not diminish with the increase of the amount of the perspiration, the total amount of solids which are eliminated by profuse sweating may be considerable.

The difference between blood which is coming from, and that which is going to, the skin, can only be concluded from the nature of the substances given out in the perspiration; but arterial blood is not rendered venous in the skin.

19. It will now be instructive to compare together in more detail than has been done in the first Lesson (§ 23), the three great organs—lungs, kidneys, and skin—which have been described.

In ultimate anatomical analysis, each of these organs consists of a moist animal membrane separating the blood from the atmosphere.

Water, carbonic acid, and solid matter pass out from the blood through the animal membrane in each organ, and constitute its secretion or excretion; but the three organs differ in the absolute and relative amounts of the constituents the escape of which they permit.

Taken by weight, water is the predominant excretion in all three; most solid matter is given off by the kidneys; most gaseous matter by the lungs.

The skin partakes of the nature of both lungs and kidneys, seeing that it absorbs oxygen and exhales carbonic acid and water, like the former, while it excretes organic and saline matter in solution, like the latter; but the skin is more closely related to the kidneys than to the lungs. Hence, as has been already said, when the free action of the skin is interrupted, its work is usually thrown upon the kidneys, and *vice versâ*. In hot weather, when the excretion by the skin increases, that of the kidneys diminishes, and the reverse is observed in cold weather.

This power of mutual substitution, however, only goes a little way; for if the kidneys be extirpated, or their functions much interfered with, death ensues, however active the skin may be. And, on the other hand, if the skin be covered with an impenetrable varnish, the temperature of the body rapidly falls, and death takes place, though the lungs and kidneys remain active.

20. The *liver* is a constant source both of loss, and, in a sense, of gain, to the blood which passes through it. It gives rise to loss, because it secretes a peculiar fluid, the *bile*, from the blood, and throws that fluid into the intestine. It is also in another way a source of loss because it elaborates from the blood passing through it a substance called *glycogen*, which is stored up sometimes in large, sometimes in small, quantities in the cells of the liver. This latter loss, however, is only temporary, and may be sooner or later converted into a gain, for this glycogen very readily passes into sugar, and either in that form or in some other way is carried off by the blood. In this respect, therefore, there is a gain to the blood of kind or quality though not of quantity of material.

The liver is the largest glandular organ in the body, ordinarily weighing about fifty or sixty ounces. It is a broad, dark, red-coloured organ, which lies on the right side of the body, immediately below the diaphragm, with which its upper surface is in contact, while its lower surface touches the intestines and the right kidney.

The liver is invested by a coat of peritoneum, which keeps it in place. It is flattened from above downwards

and convex and smooth above, where it fits into the concavity of the lower surface of the diaphragm. Flat and irregular below (Fig. 34), it is thick behind, but ends in a thin edge in front.

Viewed from below, as in Fig. 34, the *inferior vena cava*, *a*, is seen to traverse a notch in the hinder edge of the liver as it passes from the abdomen to the thorax. At *b* the trunk of the *vena portæ* is observed dividing into the chief branches which enter into, and ramify through, the substance of the organ. At *d*, the *hepatic artery*, coming almost directly from the aorta, similarly divides, enters the liver, and ramifies through it. At *c* is the single

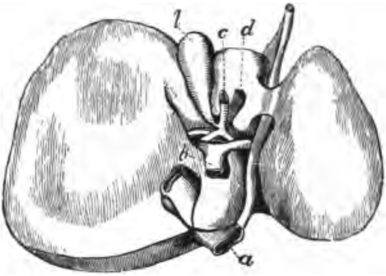

FIG. 34.—THE LIVER TURNED UP AND VIEWED FROM BELOW.

a, vena cava ; *b*, vena portæ ; *c*, bile duct ; *d*, hepatic artery ; *l*, gall-bladder. The termination of the hepatic vein in the vena cava is not seen, being covered by the piece of the vena cava.

trunk of the duct, called the *hepatic duct*, which conveys away the bile brought to it by its right and left branches from the liver. Opening into the hepatic duct is seen the duct of a large oval sac, *l*, the *gall-bladder*. The duct is smaller than the artery, and the artery than the portal vein.

If the branches of the artery, the portal vein, and the bile duct be traced into the substance of the liver, they will be found to accompany one another, and to branch out and subdivide, becoming smaller and smaller. At length the portal vein and hepatic artery (Fig. 37, *V.P.*) will be found to end in the capillaries, which traverse, like

a network, the substance of the smallest subdivisions of the liver substance visible to the naked eye—polygonal masses of one-tenth of an inch in diameter, or less, which are termed the *lobules.* Every *lobule* is seated by its base upon one of the ramifications of a great vein—the *hepatic vein*—and the blood of the capillaries of the lobule is poured into that vein by a minute veinlet, called *intralobular*

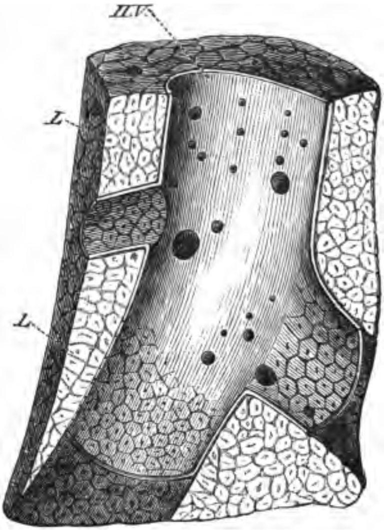

FIG. 35

A Section of part of the Liver to show *H.V.*, a branch of the hepatic vein, with *L.*, the lobules or acini of the liver, seated upon its walls, and sending their intralobular veins into it.

(Fig. 37, *H.V.*), which traverses the centre of the lobule, and pierces its base. Thus the venous blood of the portal vein and the arterial blood of the hepatic artery reach the surfaces of the lobules by the ultimate ramifications of that vein and artery, become mixed in the capillaries of each lobule, and are carried off by its *intralobular* veinlet,

which pours its contents into one of the ramifications of the hepatic vein. These ramifications, joining together, form larger and larger trunks, which at length reach the hinder margin of the liver, and finally open into the *vena cava inferior*, where it passes upwards in contact with that part of the organ.

Thus the blood with which the liver is supplied is a mixture of arterial and venous blood: the former brought by the hepatic artery directly from the aorta, the latter by the portal vein from the capillaries of the stomach, intestines, pancreas, and spleen.

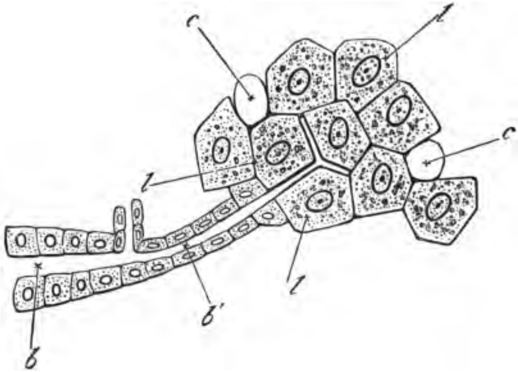

FIG. 36.

Termination of bile duct at edge of lobule (somewhat diagrammatic).

b, small bile duct, becoming still smaller at *b'*, the low flat epithelium at last suddenly changing into the hepatic cells, *l*, the channel of the bile duct being continued as small passages between the latter. *c*, capillary blood-vessel cut across.

In the lobules themselves all the meshes of the blood-vessels are occupied by the *liver cells*, or *hepatic cells*. These are many-sided minute bodies, each about $\frac{1}{1000}$th of an inch in diameter, possessing a nucleus in its interior, and frequently having larger and smaller granules of fatty matter distributed through its substance (Fig. 37, *a*). It is in the liver cells that the active powers of the liver reside.

The smaller branches of the hepatic duct, lined by an epithelium, which is continuous with that of the main duct, and thence with that of the intestines, into which the main duct opens, may be traced to the very surface of the lobules, where they seem to end abruptly. But, upon closer examination, it is found that they communicate with a network of minute passages passing between the hepatic cells, and traversing the lobule in the intervals left by the capillaries (Fig. 37, B). The bile manufactured by the hepatic cells finds its way first into these minute passages, and from them into the ducts.

21. The work of the liver, and this, as has been said, is carried out by the hepatic cells, may be considered as consisting of two kinds.

On the one hand, the hepatic cells are continually engaged in the manufacture of a complex fluid called bile, which they pour into the minute passages spoken of above, and thence into the branches of the hepatic duct; whence it flows through the duct itself into the intestines, or, when digestion is not going on and the opening of the duct into the intestine is closed, back to the gall-bladder. The materials for this bile are supplied to the hepatic cells by the blood; hence the secretion of the bile constitutes a loss to the blood.

22. The total quantity of bile secreted in the twenty-four hours varies, but probably amounts to not less than from two to three pounds. It is a golden yellow, slightly alkaline fluid, of extremely bitter taste, consisting of water with from 17 per cent. to half that quantity of solid matter in solution. The solids consist in the first place of a somewhat complex substance which may be separated out by crystallisation, as an apparently simple mass, but is in reality a mixture of two acids, in combination with soda; one called *glycocholic*, and consisting of carbon, hydrogen, nitrogen and oxygen, the other *taurocholic*, and containing, in addition to the other elements, a considerable quantity of sulphur. Besides the taurocholate and glycocholate of soda, or bile salts as the two are sometimes called, the bile contains a remarkable crystalline substance, very fatty-looking, but not really of a fatty nature, called *cholesterin*, one or more peculiar colouring matters

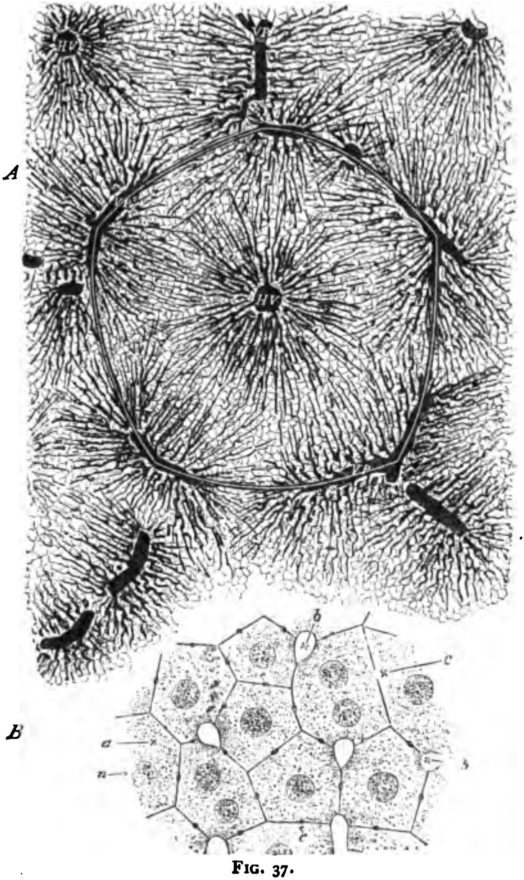

FIG. 37.

A. Section of partially injected liver magnified. The artificial white line is introduced to mark the limits of a lobule. *V.P.* Branches of portal vein breaking up into capillaries, which run towards the centre of the lobule, and join *H.V.*, the intralobular branch of the hepatic vein. The

probably related to the hæmatin of the blood, and certain saline matters.

23. Of these constituents of the bile the essential substances, the bile acids and the colouring matter, are not discoverable in blood which enters the liver; they must therefore be formed in the hepatic cells. How they are exactly formed we do not at present clearly know. The material of which they are composed is brought to the hepatic cells by the blood, but the exact condition of that material—whether, for instance, the blood brings something very like the bile acids, and only needing a slight change to be converted into bile acids; or whether the hepatic cells manufacture the bile acids from the beginning, as it were, out of the common material which the blood brings to the liver as to all other tissues and organs—is not as yet quite determined. The saline matters and cholesterin, on the other hand, appear to be present in the blood of the portal vein, and may therefore, like the water, be simply taken up by the cells from the blood, and passed on to the bile ducts.

24. Thus the bile is a continual loss to the blood. But, besides forming bile, the hepatic cells are concerned in other labours, the result of which can hardly be considered either as a loss or as a gain, since these labours simply consist in manufacturing from the blood and storing up in the hepatic cells substances which, sooner or later, are returned, generally in a changed condition, back into the blood.

As we shall presently see, the portal blood is, after a meal, heavily laden with substances, the result of the digestive changes in the alimentary canal. When these substances, carried along in the portal blood, reach the hepatic cells, in the meshes of the lobules, some of them appear to be taken up by those cells and to be stored up in them in a changed condition. In fact, the products of digestion passing along the portal veins suffer (in the liver) a further change, which has been called a secondary

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outline of the liver cells are seen as a fine network of lines throughout the whole lobule.

B. Portion of lobule very highly magnified. *a*, liver cell with *n*, nucleus (two are often present); *b*, capillaries cut across; *c*, minute biliary passages between the cells, injected with colouring matter.

digestion. Thus the liver produces a powerful effect on the quality of the blood passing through it, so that the blood in the hepatic vein is very different, especially after a meal, from the blood in the portal vein.

The changes thus effected by the hepatic cells are probably very numerous, but they have not been fully worked out, except in one particular case, which is very interesting and deserves special attention.

It is found that the liver of an animal which has been well and regularly fed, when examined immediately after death, contains a considerable quantity of a substance which is very closely allied to starch, consisting of carbon, hydrogen, and oxygen in certain proportions. This substance, which may by proper methods be extracted and preserved as a white powder, is in fact an *animal starch*, and is called *glycogen.* As we shall see, common starch is readily changed by certain agents into grape-sugar, dextrose or glucose, as it is sometimes called; and this glycogen is similarly converted with ease into grape-sugar. Indeed, if the liver of such an animal as the above, instead of being examined immediately after death, be left in the body, or be placed on one side after removal from the body for some hours before it is examined, a great deal of the glycogen will have disappeared, a quantity of grape-sugar having taken its place. There seems to be present in the liver some agent capable of converting the glycogen into grape-sugar, and this change is particularly apt to take place if the liver is kept at blood-heat or near that temperature.

Now if, instead of the liver of a well-fed animal, the liver of an animal which has been starved for several days be examined in the same way, very little glycogen indeed will be found in it, and when the liver is left exposed to warmth for some time very little grape-sugar is found. That is to say, the liver has, in the first case, formed the glycogen and stored it up in itself, out of the food brought to it by the portal blood: in the second case, no food has been brought to the liver from the alimentary canal, no glycogen has been formed, and none stored up. If the liver in the first case be examined microscopically with certain precautions, the glycogen may be seen stored up in the hepatic cells; in the second case little or none can be seen.

The kind of food which best promotes the storing up of glycogen in the liver is one containing starch or sugar; but some glycogen will make its appearance even when an animal is fed on an exclusively proteid diet, though not nearly so much as when starch or sugar is given.

It would appear, then, that the hepatic cells can manufacture and store up in themselves the substance glycogen, being able to make it out of even proteid matter, but more easily making it out of sugar; for, as we shall see, all the starch which is eaten as food is converted into sugar in the alimentary canal, and reaches the liver as sugar.

There are reasons for thinking that the glycogen, thus deposited and stored up in the liver, is converted into sugar little by little as it is wanted, poured into the hepatic vein, and thus distributed over the body. So that we may regard this remarkable formation of glycogen in the liver as an act by which the blood, when it is over-rich in sugar, as after a meal, stores it up or deposits it in the liver as glycogen; and then, in the intervals between meals, the liver deals out the stored-up material as sugar back again in driblets to the blood. The loss to the blood, therefore, is temporary—no more a real loss than when a man deposits at his banker's some money which he has received until he has need to spend it.

This story of glycogen, important in itself, is also useful as indicating other possible effects of a similar nature which the hepatic cells may bring about on the blood, as it is passing in the meshes of the lobules of the liver from the veinlets of the portal to the veinlets of the hepatic vein.

25. We must next consider the chief sources of constant gain to the blood; and, in the first place, *the sources of gain of matter*.

The lungs and skin are, as has been seen, two of the principal channels by which the body loses liquid and gaseous matter, but they are also the sole means by which one of the most important of all substances for the maintenance of life, *oxygen*, is introduced into the blood. It has already been pointed out that the volume of the oxygen taken into the blood by the lungs is rather greater than that of the carbonic acid given out. The absolute weight of oxygen thus absorbed may be estimated at 10,000 grains (see Lesson VI. § 2).

How much is taken in by the skin of man is not certainly known, but in some of the lower animals, such as the frog, the skin plays a very important part in the performance of the respiratory function.

26. The *lymphatic system* has been already mentioned as a feeder of the blood with a fluid which, in general, appears to be merely the superfluous drainage, as it were, of the blood-vessels: though at intervals, as we shall see, the lacteals make substantial additions of new matter. It is very probable that the multitudinous *lymphatic glands* may effect some change in the fluid which traverses them, or may add to the number of corpuscles in the lymph.

Nothing *certain* is known of the functions of certain bodies which are sometimes called ductless glands, but have quite a different structure from ordinary secreting glands; and indeed do not resemble each other in structure. These are, the *thyroid body*, which lies in the part of the throat below the larynx, and is that organ which, when enlarged by disease, gives rise to "Derbyshire neck" or "goître"; the *thymus body*, situated at the base of the heart, largest in infants, and gradually disappearing in adult, or old persons; and the *supra-renal bodies*, which lie above the kidneys.

27. We are as much in the dark respecting the office of the large viscus called the *spleen*, which lies upon the left side of the stomach in the abdominal cavity (Fig. 38). It is an elongated, flattened, red body, abundantly supplied with blood by an artery called the *splenic artery*, which proceeds almost directly from the aorta. The blood which has traversed the spleen is collected by the *splenic vein*, and is carried by it to the *vena portæ*, and so to the liver.

A section of the spleen shows a dark red spongy mass dotted over with minute whitish spots. Each of these last is the section of one of the spheroidal bodies called *corpuscles of the spleen*, which are scattered through its substance, and consist of a solid aggregation of minute bodies, like the white corpuscles of the blood, traversed by a capillary network, which is fed by a small twig of the splenic artery. The dark red part of the spleen, in which these white spots are embedded, is composed of a spongy framework of fibrous and elastic tissue, frequently mixed with plain muscular fibres, and of peculiar

delicate vascular structures, which fill up the meshes of the framework, and through which the splenic blood flows.

The elasticity of the splenic tissue allows the organ to be readily distended with blood, and enables it to return to its former size after distension. It appears to change its dimensions with the state of the abdominal viscera, attaining its largest size about six hours after a full meal, and falling to its minimum bulk six or seven hours later, if no further supply of food be taken.

The blood of the splenic vein is found to contain proportionally fewer red corpuscles, but more colourless corpuscles, than in the splenic artery; and it has been

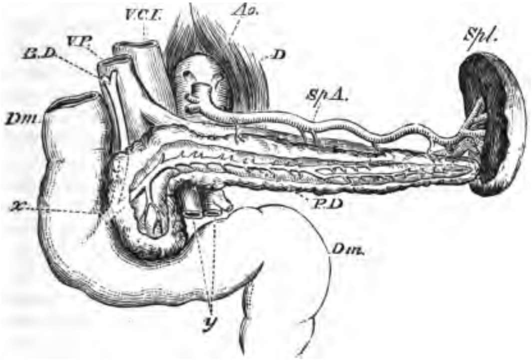

FIG. 38.

The spleen (*Spl*) with the splenic artery (*Sp A.*). Below this is seen the splenic vein running to help to form the vena portæ (*V.P.*). *Ao*, the aorta. *D*, a pillar of the diaphragm; *P.D*, the pancreatic duct exposed by dissection in the substance of the pancreas: *Dm*, the duodenum; *B.D*, the biliary duct uniting with the pancreatic duct into the common duct, *x*; *y*, the intestinal vessels.

supposed that the spleen is one of those parts of the economy in which, on the one hand, colourless corpuscles of the blood are produced, and, on the other, red corpuscles die and are broken up.

28. It has been seen that *heat* is being constantly given off from the integument and from the air-passages; and

everything that passes from the body carries away with it, in like manner, a certain quantity of heat. Furthermore, the surface of the body is much more exposed to cold than its interior. Nevertheless, the temperature of the body is in health maintained very evenly, at all times and in all parts, within the range of two degrees or even less on either side of 99° Fahrenheit.

This is the result of three conditions:—the first, that heat is constantly being generated in the body; the second, that it is as constantly being distributed through the body; the third, that it is subject to incessant regulation.

Heat is generated whenever oxidation takes place. As we have seen, the tissues all over the body, muscle, brain-substance, gland cells and the like, are continually undergoing oxidation. The living substance of the tissue, built up out of the complex proteids, fats, and carbo-hydrates, and thus even still more complex than these, is, by means of the oxygen brought by the arterial blood, oxidised, and broken down into simpler more oxidised bodies, which are eventually reduced to urea, carbonic acid, and water. Wherever life is being manifested these oxidative changes are going on, more energetically in some places, in some tissues, and in some organs, than in others; and similar changes, though perhaps not to any very great extent, are taking place in the blood itself. Hence every capillary vessel and every extra-vascular islet of tissue is really a small fireplace in which heat is being evolved, in proportion to the activity of the chemical changes which are going on.

29. But as the vital activities of different parts of the body, and of the whole body, at different times, are very different; and as some parts of the body are so situated as to lose their heat by radiation and conduction much more easily than others, the temperature of the body would be very unequal in its different parts, and at different times, were it not for the arrangement by which the heat is distributed and regulated.

Whatever oxidation occurs in any part, raises the temperature of the blood which is in that part at the time, to a proportional extent. But this blood is swiftly hurried away into other regions of the body, and rapidly gives up its increased temperature to them. On the other hand,

the blood which, by being carried to the vessels in the skin on the surface of the body begins to have its temperature lowered by evaporation, radiation, and conduction, is hurried away, before it has time to get thoroughly cooled, into the deeper organs; and in them it becomes warm by contact, as well as by the oxidating processes there going on. Thus the blood-vessels and their contents might be compared to a system of hot-water pipes, through which the warm water is kept constantly circulating by a pump; while it is heated not by a great central boiler as usual, but by a multitude of minute gas jets, disposed beneath the pipes, not evenly, but more here and fewer there. It is obvious that, however much greater might be the heat applied to one part of the system of pipes than to another, the general temperature of the water would be even throughout, if it were kept moving with sufficient quickness by the pump.

30. If such a system were entirely composed of closed pipes, the temperature of the water might be raised to any extent by the gas jets. On the other hand, it might be kept down to any required degree by causing a larger, or smaller, portion of the pipes to be wetted with water, which should be able to evaporate freely—as, for example, by wrapping them in wet cloths. And the greater the quantity of water thus evaporated, the lower would be the temperature of the whole apparatus.

Now, the regulation of the temperature of the human body is effected on this principle. The vessels are closed pipes, but a great number of them are inclosed in the skin and in the mucous membrane of the air-passages, which are, in a physical sense, wet cloths freely exposed to the air. It is the evaporation from these which exercises a more important influence than any other condition upon the regulation of the temperature of the blood, and, consequently, of the body.

But, as a further nicety of adjustment, the wetness of the regulator is itself determined, through the aid of the nervous system, by the temperature of the body. The sweat-glands are so constituted that they are stimulated to activity by warmth and rendered inactive by cold. When the body is exposed to a high temperature (and the same occurs when a part only of the body is heated) the

action of certain nerves causes the sweat-glands to pour forth a copious secretion on to the skin; and when the temperature falls, the glands cease to act. Moreover, in this work of secreting sweat, the sweat-glands are assisted by corresponding changes in the blood-vessels of the skin. It has been stated (see Lesson II., § 23) that the small arteries of the body may be sometimes narrowed or constricted, and sometimes widened or dilated. Now the condition of the small arteries, whether they are constricted or dilated, depends, as we have also seen, upon the action of certain nerves (vaso-motor nerves). And it appears that when the body is exposed to a high temperature these nerves are so affected as to lead to a dilatation of small arteries of the skin; but when these are dilated the capillaries and small veins in which they end become much fuller of blood, and from these filled and swollen capillaries much more nutritive matter passes through the capillary walls to the sweat-glands, so that these have more abundant material from which to manufacture sweat. On the other hand, when the body is lowered in temperature the vaso-motor nerves are so affected that the small arteries of the skin are constricted; hence less blood enters the capillaries of the skin, and less material is brought to the sweat-glands.

Thus when the temperature is raised two things happen, both brought about by the nervous system. In the first place, the arteries of the skin are widened so that a much larger proportion of the total blood of the body is carried to the surface of the skin and there becomes cooled; and, secondly, this cooling process is greatly helped by the increased evaporation resulting from the increased action of the sweat-glands, whose activity is further favoured by the presence in the skin of so much blood. Conversely when the temperature is lowered, less of the blood is brought to the skin, and more of the blood circulates through the deeper, hotter parts of the body, and the sweat-glands cease their work (this quiescence of theirs being in turn favoured by the lessened blood-supply); hence the evaporation is largely diminished, and thus the blood is much less cooled.

Hence it is that, so long as the surface of the body perspires freely, and the air-passages are abundantly moist, a

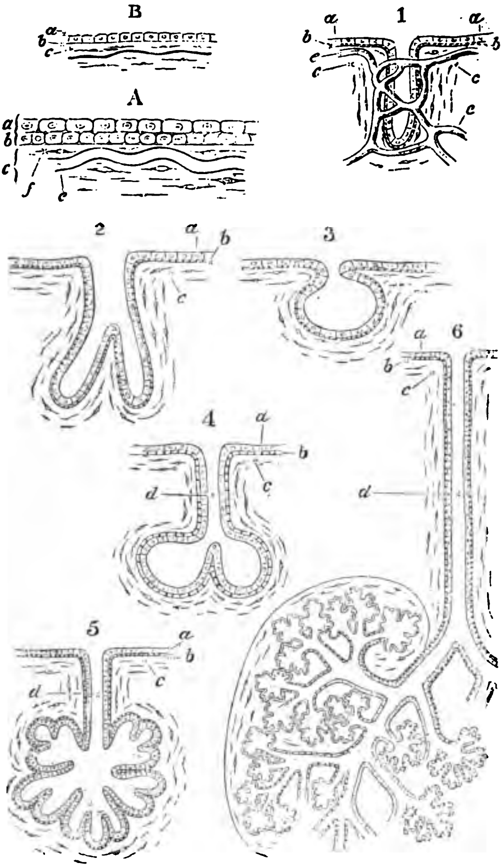

FIG. 39.—A DIAGRAM TO ILLUSTRATE THE STRUCTURE OF GLANDS.

A. Typical structure of the mucous membrane. *a*, an upper, and *b* a lower, layer of epithelium cells; *c*, the dermis with *e*, a blood-vessel, and *f*, connective tisue corpuscles.

man may remain with impunity, for a considerable time, in an oven in which meat is being cooked. The heat of the air is expended in converting this superabundant perspiration into vapour, and the temperature of the man's blood is hardly raised.

31. Among the *sources of loss* to the blood which come into operation at intervals only, the most important are the glands proper, all of which are, in principle, narrow pouches of the mucous membranes, or of the integument of the body, lined by a continuation of the epithelium, or of the epidermis. In the *glands of Lieberkühn*, which exist in immense numbers in the walls of the small intestines, each gland is nothing more than a simple blind sac of the mucous membrane, shaped like a small test-tube, with its closed ends outwards, and its open end on the inner surface of the intestine (Fig. 39, 1). The sweat-glands of the skin, as we have already seen, are equally simple, blind, tube-like involutions of the integument, the ends of which become coiled up. The *sebaceous glands*, usually connected with the air sacs, are shorter, and their blind ends are somewhat subdivided, so that the gland is divided into a narrow neck and a more dilated and sacculated end (Fig. 39, 5). The neck by which the gland communicates with the free surface is called its *duct*. More complicated glands are produced by the elongation of the duct into a long tube, and the division and subdivision of the blind ends into multitudes of similar tubes, each of which ends in a dilatation (Fig. 39, 6). These dilatations, attached to their branched ducts, somewhat resemble a bunch of grapes. Glands of this kind are called *racemose*. The *salivary glands* and the *pancreas* are such glands.

Now, many of these glands, such as the salivary, and the pancreas (with the perspiratory, or sudoriparous glands,

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B. The same, with only one layer of cells, *a* and *b*, the so-called basement membrane between the epithelium *a*, and dermis *c*.
1. A simple tubular gland.
2. A turbular gland bifid at its base. In this and succeeding figures the blood-vessels are omitted.
3. A simple saccular gland.
4. A divided saccular gland, with a duct, *d*.
5. A similar gland still more divided.
6. A racemose gland, part only being drawn.

which it has been convenient to consider already), are only active when certain impressions on the nervous system give rise to a peculiar condition of the gland, or of its vessels, or of both.

Thus the sight or smell, or even the thought of food, will cause a flow of saliva into the mouth: the previously quiescent gland suddenly pouring out its fluid secretion, as a result of a change in the condition of the nervous system. And, in animals, a salivary gland can be made to secrete abundantly, by irritating a nerve which supplies the gland and its vessels. This effect may be shown by experimental evidence to be the result of a direct influence of the nerve on the cells of the gland. What takes place is somewhat as follows. As we shall see (Lesson VII.), whenever a nerve is irritated, or "stimulated," at any point, as for example by an electric shock, a change takes place in the condition of the substance of the nerve at the point of irritation. This change is propagated from particle to particle of the nervous matter, and thus travels along the nerve-fibres as a *nervous impulse*. When the nerve of the salivary gland is irritated, the nervous impulse, thus started, travelling along the nerve reaches the cells of the gland and sets up, in turn, changes in their substance. The chief result of these changes in the cells of the gland is the formation of a certain quantity of salivary fluid, which, as the *secretion* of the gland, passes from the cells into the ducts.

We shall see (Lesson VII.) that if a nerve which goes to a muscle is irritated, a nervous impulse is transmitted in the same way to the substance of the fibres of the muscle, and gives rise to chemical changes in that substance. One result of these changes is the evolution of carbonic acid (§ 32), which might, therefore, be called a *secretion* of the muscle. In the case of the muscle the chemical changes are accompanied by a change of form, the fibres shortening and becoming correspondingly thicker, while the products of the chemical changes are returned to the blood and are spoken of as waste. In the secreting cell there is no appreciable change of form, and the products of the chemical change, which are conspicuous and important, pass, not into the blood, but, accompanied by much water, into the duct of the gland.

In the salivary gland, as in the sudoriparous gland, this direct action of the nerve upon the gland is further assisted by the fact that the stimulation of the nerve leads at the same time to a widening of the arteries of the gland, whereby the active cells are supplied more richly with material for manufacturing their secretion.

The liquids poured out by these glands are always very poor in solid constituents, and consist largely of water. Those poured on to the surface of the body are lost, but those which are received by the alimentary canal are doubtless in a great measure re-absorbed.

32. A great intermittent *source of gain* to the blood is to be found in the muscles, every contraction of which is accompanied by a pouring of certain waste products into the blood. Even when they are apparently at rest the muscles are always pouring waste matters into the blood; but the amount of material which they thus give back to the blood is under the circumstances not greater than, indeed, at times, perhaps less than, the amount of nutritive material which they take from the blood; the activity of a muscle, however, greatly increases the proportion of its waste products. That much of this waste is carbonic acid is certain from the facts (*a*) that the blood which leaves a contracting muscle is always highly venous, far more so than that which leaves a quiescent muscle; (*b*) that muscular exertion at once immensely increases the quantity of carbonic acid expired; but whether the amount of nitrogenous waste is increased under the circumstances, or not, is a point yet under discussion.

LESSON VI.

THE FUNCTION OF ALIMENTATION.

1. THE great source of gain to the blood, and, except the lungs, the only channel by which altogether new material is introduced into that fluid, putting aside the altogether exceptional case of absorption by the skin, is the *alimentary canal*, the totality of the operations of which constitutes the function of *alimentation*. It will be useful to consider the general nature and results of the performance of this function before studying its details.

2. A man daily takes into his mouth and thereby introduces into his alimentary canal, a certain quantity of solid and liquid food, in the shape of meat, bread, butter, water, and the like. The amount of chemically dry, solid matter, which must thus be taken into the body if a man of average size and activity is neither to lose, nor to gain, in weight, has been found to be about 8,000 grains. In addition to this, his blood absorbs by the lungs about 10,000 grains of oxygen gas, making a grand total of 18,000 grains (or nearly two pounds and three-quarters avoirdupois) of daily gain of dry, solid and gaseous matter.

3. The weight of dry solid matter passed out from the alimentary canal does not, on the average, amount to more than one-tenth of that which is taken into it, or 800 grains. Now the alimentary canal is the only channel by which any appreciable amount of solid matter leaves the body in an undissolved condition. It follows, therefore, that in

addition to the 10,000 grains of oxygen, the equivalent of 7,200 grains of dry, solid, matter must pass out of the body by the lungs, skin, or kidneys, either in the form of gas, or dissolved in the liquid excretions of those organs. Further, as the general composition of the body remains constant, it follows either that the elementary constituents of the solids taken into the body must be identical with those of the body itself: or that, in the course of the vital processes, the food alone is destroyed, the substance of the body remaining unchanged: or, finally, that both these alternatives hold good, and that food is, partly, identical with the wasting substance of the body, and replaces it; and, partly, differs from the wasting substance, and is consumed without replacing it.

4. As a matter of fact, all the substances which are used as food come under one of four heads. They are either what may be termed *Proteids*, or they are *Fats*, or they are *Amyloids*, also called *Carbohydrates*, or they are *Minerals*.

Proteids are composed of the four elements—carbon, hydrogen, oxygen, and nitrogen, sometimes united with sulphur and phosphorus.

Under this head come, the so-called *Gluten* of flour; the *Albumin* of white of egg, and blood serum; the *Fibrin* of the blood; the substance, which is the chief constituent of muscle and flesh, and which is called *Myosin*, or when slightly altered, *Syntonin;* the *Casein* of milk and of cheese, and many other similar but less common bodies; while *Gelatin*, which is obtained by boiling from connective tissue and by special means from bones, and *Chondrin*, which may be produced in the same way from cartilage, may be considered to be outlying members of the same group.

Fats are composed of carbon, hydrogen, and oxygen only, and contain more hydrogen than is enough to form water if united with the oxygen which they possess.

All vegetable and animal fatty matters and oils come under this division.

Amyloids or *carbohydrates* are substances which also consist of carbon, hydrogen, and oxygen only. But they contain no more hydrogen than is just sufficient to produce water with their oxygen. These are the matters

known as *Starch*, *Dextrine*, *Sugar;* and closely allied to them are the various *Gums.*

It is the peculiarity of the three groups of food-stuffs just mentioned that they can only be obtained (at any rate, at present) by the activity of living beings, whether animals or plants, so that they may be conveniently termed *vital food-stuffs.*

Food-stuffs of the fourth class, on the other hand, or *Minerals*, are to be procured as well from the not-living, as the living world. They are *water*, and *salts* of sundry alkalies, earths, and metals. To these, in strictness, *oxygen* ought to be added, though, as it is not taken in by the alimentary canal, it hardly comes within the ordinary acceptation of the word food.

5. In ultimate analysis, then, it appears that *vital food-stuffs* contain either three or four of the elements, carbon, hydrogen, oxygen, and nitrogen; and that *mineral food-stuffs* are water and salts. But the human body, in ultimate analysis, also proves to be composed of the same four elements, *plus* water, and the same saline matters as are found in food.

More than this, no substance can serve permanently for food—that is to say, can prevent loss of weight and change in the general composition of the body—unless it contains a certain amount of proteid matter in the shape of albumin, casein, &c., &c., while, on the other hand, any substance which contains proteid matter in a readily assimilable shape. is competent to act as a permanent vital food-stuff.

The human body, as we have seen, contains a large quantity of proteid matter in one or other of the forms which have been enumerated; and, therefore, it turns out to be an indispensable condition, that every substance which is to serve permanently as food, must contain a sufficient quantity of the most important and complex component of the body ready made. It must also contain a sufficient quantity of the mineral ingredients which are required. Whether it contains either fats or amyloids, or both, its essential power of supporting the life and maintaining the weight and composition of the body remains unchanged.

6. The necessity of constantly renewing the supply of

proteid matter arises from the circumstance that whether the body is fed or not, a breaking down of proteid material is continually going on, giving rise to a constant nitrogenous waste, which leaves the body in the form of urea. Now, this nitrogenous waste, coming from the breaking down of proteid material, can only be met by fresh proteid material being supplied. If proteid matter be not supplied, the body must needs waste, because there is nothing in the food competent to make good the nitrogenous loss.

On the other hand, if proteid matter be supplied, there can be no absolute necessity for any other but the mineral food-stuffs, because proteid matter contains carbon and hydrogen in abundance, and hence is competent to make good not only the breaking down which is indicated by the nitrogenous loss, but also that which is indicated by the other great products of waste, carbonic acid and water.

In fact, the final results of the oxidation of proteid matters are carbonic acid, water, and ammonia; and these, as we have seen, are the final shapes of the waste products of the human economy.

7. From what has been said, it becomes readily intelligible that, whether an animal be herbivorous or carnivorous, it begins to starve from the moment its vital food-stuffs consist of pure amyloids, or fats, or any mixture of them. It suffers from what may be called *nitrogen starvation*, and, sooner or later, will die.

In this case, and still more in that of an animal deprived of vital food altogether, the organism, so long as it continues to live, feeds upon itself. In the former case, all the processes involving a loss of nitrogen, in the latter, all the processes leading to the appearance of all the several waste products, are necessarily carried on at the expense of its own body; whence it has been rightly enough observed that a starving sheep is as much a carnivore as a lion.

8. But though proteid matter is the essential element of food, and under certain circumstances may suffice by itself to maintain the body, it is a very disadvantageous and uneconomical food.

Albumin, which may be taken as a type of the proteids,

contains about 53 parts of carbon and 15 of nitrogen in 100 parts. If a man were to be fed on white of egg, therefore, he would take in, speaking roughly, 3½ parts of carbon for every part of nitrogen.

But it is proved experimentally that a healthy, full-grown man, keeping up his weight and heat, and taking a fair amount of exercise, eliminates per diem 4,000 grains of carbon to only 300 grains of nitrogen, or, roughly, only needs one-thirteenth as much nitrogen as carbon. However, if he is to get his 4,000 grains of carbon out of albumin, he must eat 7,547 grains of that substance. But 7,547 grains of albumin contain 1,132 grains of nitrogen, or nearly four times as much as he wants.

To put the case in another way, it takes about four pounds of fatless meat (which generally contains about one-fourth its weight of dry solid proteids) to yield 4,000 grains of carbon, whereas one pound will furnish 300 grains of nitrogen.

Thus a man confined to a purely proteid diet must eat a prodigious quantity of it. This not only involves a great amount of physiological labour in comminuting the food, and a great expenditure of power and time in dissolving and absorbing it, but throws a great quantity of wholly profitless labour upon those excretory organs, which have to get rid of the nitrogenous matter, three-fourths of which, as we have seen, is superfluous.

Unproductive labour is as much to be avoided in physiological as in political economy; and it is quite possible that an animal fed with perfectly nutritious proteid matter should die of starvation; the loss of power in various operations required for its assimilation overbalancing the gain; or the time occupied in their performance being too great to permit waste to be repaired with sufficient rapidity. The body, under these circumstances, falls into the condition of a merchant who has abundant assets, but who cannot get in his debts in time to meet his creditors.

9. These considerations lead us to the physiological justification of the universal practice of mankind in adopting a mixed diet, in which proteids are mixed either with fats or with amyloids, or with both.

Fats may be taken to contain about 80 per cent. of

carbon, and amyloids about 40 per cent. Now it has been seen that there is enough nitrogen to supply the waste of that substance per diem, in a healthy man, in a pound of fatless meat, which also contains 1,000 grains of carbon, leaving a deficit of 3,000 grains of carbon. Rather more than half a pound of fat, or a pound of sugar, will supply this quantity of carbon.

10. Several apparently simple articles of food constitute a mixed diet in themselves. Thus butcher's meat commonly contains from 30 to 50 per cent. of fat. Bread, on the other hand, contains the proteid gluten, and the amyloids, starch and sugar, with minute quantities of fat. But from the proportion in which these proteid and other constituents exist in these substances, they are neither, taken alone, such physiologically economical foods as they are when combined in the proportion of about 200 to 75, or two pounds of bread to three-quarters of a pound of meat per diem.[1]

11. It is quite certain that nine-tenths of the dry, solid food which is taken into the body, sooner or later leaves it in the shape of carbonic acid, water, and urea; and it is also certain not only that the compounds which leave the body are more highly oxidised than those which enter it, but that all the oxygen taken into the blood by the lungs is carried away out of the body in the various waste products.

The intermediate stages of this conversion are, however, by no means so clear. It is highly probable that all the food-stuffs which pass from the alimentary canal into the blood, be they proteids, or fats, or amyloids, become part and parcel of some tissue or other (muscle, nervous tissue, glandular tissue, and the like), before they are oxidised; that indeed it is as constituent elements of some tissue or other that they suffer oxidation, and that

[1] It may be worth while to point out that mere chemical analysis is however, by itself, a very insufficient guide as to the usefulness and nutritive value of an article of food. A substance to be nutritious must not only contain some or other of the above food-stuffs, but contain them in an available, that is a digestible form. A piece of beef-steak is far more nourishing, than a quantity of pease pudding containing even a larger proportion of proteid material, because the former is far more digestible than the latter; and a small piece of dry hard cheese, though of high nutritive value as judged by mere chemical analysis, will not satisfy the more subtle criticism of the stomach.

the amount of oxidation going on in the blood is very small. But this view, though probable, is not strictly proved; at all events, we cannot at present say exactly how much oxidation takes place in the blood, or even whether any takes place at all. Further, it is probable that, under certain circumstances, the food may suffer some amount of oxidation in the alimentary canal itself.

In the course of its oxidation, the food not only supplies the energy which the body expends in doing work, but also the energy which, as we have seen, the body loses as heat. The oxidation of the food is indeed the ultimate source of the heat of our bodies, all other causes being of little moment. About this there can be no doubt, and it is further probable that the oxidation which thus gives rise to heat is not the oxidation of the elements of the food as they are carried about in the blood, but the oxidation of the tissues, more especially the muscles, into which the food-stuffs have been built up, and of which they have become an integral part.

12. Food-stuffs have been divided into *heat-producers* and *tissue-formers*—the amyloids and fats constituting the former division, the proteids the latter. But this is a very misleading, and indeed erroneous classification, inasmuch as it implies, on the one hand, that the oxidation of the proteids does not develop heat; and, on the other, that the amyloids and fats, in being oxidised, subserve only the production of heat.

Undoubtedly proteids are *tissue-formers*, inasmuch as no tissue can be produced without them; for all the tissues are nitrogenous, some containing a large and others a small quantity of nitrogen, and proteids are the only nitrogenous food-stuffs; they alone can supply the nitrogenous elements of the tissues. But there is reason to think that the fats and amyloids taken as food may also be directly built up into the tissues. As we have seen, when a muscle contracts, while there is abundant evidence of carbonaceous waste, there is not such clear evidence of nitrogenous waste; that is to say, the non-nitrogenous part of the tissue seems to be used up more quickly than the nitrogenous part; and the consumption of this particular constituent of the muscular substance may be made good by non-nitrogenous food, by fats or amyloids,

On the other hand, proteids must be regarded as heat-producers also. Even if food be oxidised in the blood, proteids, in being oxidised, will give rise to heat. And if oxidation be, as has been suggested, largely confined to the tissues, though in some tissues, as in muscles, the non-nitrogenous part seems to be most rapidly changed, yet the nitrogenous part, supplied by the proteids, is sooner or later oxidised, and in being oxidised must give rise to heat.

As soon as the elements of the food, in fact, get into the blood, the distinction between the two classes is lost; both form tissues, and both supply heat.

If it is worth while to make a special classification of the vital food-stuffs at all, it appears desirable to distinguish the *essential* food-stuffs, or proteids, from the *accessory* food-stuffs, or fats and amyloids—the former alone being, in the nature of things, necessary to life, while the latter, however important, are not absolutely necessary.

13. All food-stuffs being thus proteids, fats, amyloids, or mineral matters, pure or mixed up with other substances, the whole purpose of the alimentary apparatus is to separate these proteids, &c., from the innutritious residue, if there be any, and to reduce them into a condition either of solution or of excessively fine subdivision, in order that they may make their way through the delicate structures which form the walls of the vessels of the alimentary canal. To these ends food is taken into the mouth and masticated, is mixed with saliva, is swallowed, undergoes gastric digestion, passes into the intestine, and is subjected to the action of the secretions of the glands attached to that viscus; and, finally, after the more or less complete extraction of the nutritive constituents, the residue, mixed up with certain secretions of the intestines, leaves the body as the *fæces*.

The cavity of the mouth is a chamber with a fixed roof, formed by the hard *palate* (Fig. 40, *l*), and with a moveable floor, constituted by the lower jaw, and the tongue (*k*), which fills up the space between the two branches of the jaw. Arching round the margins of the upper and the lower jaws are the thirty-two teeth, sixteen above and sixteen below, and, external to these, the closure of the

cavity of the mouth is completed by the cheeks at the sides, and by the lips in front.

When the mouth is shut the back of the tongue comes into close contact with the palate; and, where the hard

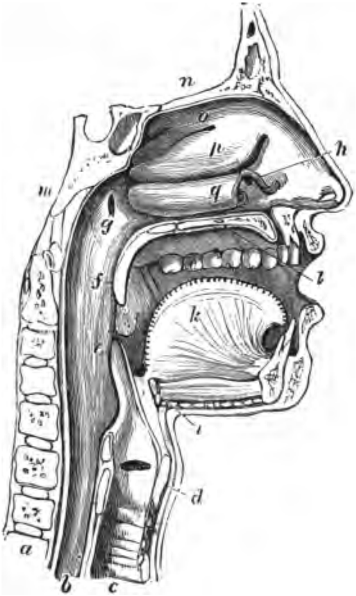


FIG. 40.

A SECTION OF THE MOUTH AND NOSE TAKEN VERTICALLY, A LITTLE TO THE LEFT OF THE MIDDLE LINE.

a, the vertical column; *b*, the gullet; *c*, the wind-pipe; *d*, the thyroid cartilage of the larynx; *e*, the epiglottis; *f*, the uvula; *g*, the opening of the left Eustachian tube; *h*, the opening of the left lachrymal duct; *i*, the hyoid bone; *k*, the tongue; *l*, the hard palate; *m*, *n*, the base of the skull; *o*, *p*, *q*, the superior, middle, and inferior turbinal bones. The letters *g*, *f*, *e*, are placed in the pharynx.

palate ends, the communication between the mouth and the back of the throat is still further impeded by a sort of

fleshy curtain—the soft *palate* or *velum*—the middle of which is produced into a prolongation, the *uvula* (*f*), while its sides, skirting the sides of the passage, or *fauces*, form double muscular pillars, which are termed the *pillars of the fauces.* Between these the *tonsils* are situated, one on each side.

The velum with its uvula comes into contact below with the upper part of the back of the tongue, and with a sort of gristly, lid-like process connected with its base, the *epiglottis* (*e*).

Behind the partition thus formed lies the cavity of the *pharynx*, which may be described as a funnel-shaped bag with muscular walls, the upper margins of the slanting, wide end of which are attached to the base of the skull, while the lateral margins are continuous with the sides, and the lower with the floor, of the mouth. The narrow end of the pharyngeal bag passes into the gullet or œsophagus (*b*), a muscular tube, which affords a passage into the stomach.

There are no fewer than six distinct openings into the front part of the pharynx—four in pairs, and two single ones in the middle line. The two pairs are, in front, the hinder openings of the nasal cavities; and at the sides, close to these, the apertures of the *Eustachian tubes* (*g*). The two single apertures are, the hinder opening of the mouth between the soft palate and the epiglottis; and, behind the epiglottis, the upper aperture of the respiratory passage, or the *glottis*.

14. The mucous membrane which lines the mouth and the pharynx is beset with minute glands, the *buccal glands;* but the great glands from which the cavity of the mouth receives its chief secretion are the three pairs which, as has been already mentioned, are called *parotid*, *submaxillary*, *sublingual*, and which secrete the principal part of the saliva (Fig. 41).

Each parotid gland is placed just in front of the ear, and its duct passes forwards along the cheek, until it opens in the interior of the mouth, opposite the second upper grinding tooth.

The submaxillary and sublingual glands lie between the lower jaw and the floor of the mouth, the submaxillary being situated further back than the sublingual. Their

ducts open in the floor of the mouth below the tip of the tongue. The secretion of these salivary glands, mixed with that of the small glands of the mouth, constitutes the *saliva*—a fluid which, though thin and watery, contains a small quantity of animal matter, called *Ptyalin*, which has certain very peculiar properties. It does not act upon proteid food-stuffs, nor upon fats; but if mixed with starch, and kept at a moderate warm temperature, it turns that starch into grape sugar. The importance of this operation becomes apparent when one reflects that starch is insoluble, and therefore, as such, useless as

FIG. 41.

A dissection of the right side of the face, showing, *a*, the sublingual, *b*, the submaxillary glands, with their ducts opening beside the tongue in the floor of the mouth at *d*; *c*, the parotid gland and its duct, which opens on the side of the cheek at *e*.

nutriment, while sugar is highly soluble, and readily passes through the walls of the alimentary canal.

15. Each of the thirty-two teeth which have been mentioned consists of a *crown* which projects above the gum, and of one or more *fangs*, which are embedded in sockets, or what are called *alveoli*, in the jaws.

The eight teeth on opposite sides of the same jaw are constructed upon exactly similar patterns, while the eight

teeth which are opposite to one another, and bite against one another above and below, though similar in kind, differ somewhat in the details of their patterns.

The two teeth in each eight which are nearest the middle line in the front of the jaw, have wide but sharp and chisel-like edges. Hence they are called *incisors*, or cutting teeth. The tooth which comes next is a tooth with a more conical and pointed crown. It answers to the great tearing and holding tooth of the dog, and is called the *canine* or eye-tooth. The next two teeth have broader crowns, with two cusps, or points, on each crown, one on the inside and one on the outside, whence they are termed *bicuspid* teeth, and sometimes false grinders. All these teeth have usually one fang each, except the bicuspid, the fangs of which may be more or less completely divided into two. The remaining teeth have two or three fangs each, and their crowns are much broader. As they crush and grind the matters which pass between them they are called *molars*, or true grinders. In the upper jaw their crowns present four points at the four corners, and a diagonal ridge connecting two of them. In the lower jaw the complete pattern is five-pointed, there being two cusps on the inner side and three on the outer.

The muscles of the parts which have been described have such a disposition that the lower jaw can be depressed, so as to open the mouth and separate the teeth; or raised, in such a manner as to bring the teeth together; or more obliquely from side to side, so as to cause the face of the grinding teeth and the edges of the cutting teeth to slide over one another. And the muscles which perform the elevating and sliding movements are of great strength, and confer a corresponding force upon the grinding and cutting actions of the teeth. In correspondence with the pressure they have to resist, the superficial substance of the crown of the teeth is of great hardness, being formed of *enamel*, which is the hardest substance in the body, so dense and hard, indeed, that it will strike fire with steel (see Lesson XII.). But notwithstanding its extreme hardness, it becomes worn down in old persons, and, at an earlier age, in savages who live on coarse food.

16. When solid food is taken into the mouth, it is cut and ground by the teeth, the fragments which ooze out upon the outer side of their crowns being pushed beneath them again by the muscular contractions of the cheeks and lips; while those which escape on the inner side are thrust back by the tongue, until the whole is thoroughly rubbed down.

While mastication is proceeding, the salivary glands pour out their secretion in great abundance, and the saliva mixed with the food, which thus becomes interpenetrated not only with the salivary fluid, but with the air which is entangled in the bubbles of the saliva.

When the food is sufficiently ground it is collected, enveloped in saliva, into a mass or bolus, which rests upon the back of the tongue, and is carried backwards to the aperture which leads into the pharynx. Through this it is thrust, the soft palate being lifted and its pillars being brought together, while the backward movement of the tongue at once propels the mass and causes the epiglottis to incline backwards and downwards over the glottis, and so to form a bridge by which the bolus can travel over the opening of the air-passage without any risk of tumbling into it. While the epiglottis directs the course of the mass of food below, and prevents it from passing into the trachea, the soft palate guides it above, keeps it out of the nasal chamber, and directs it downwards and backwards towards the lower part of the muscular pharyngeal funnel. By this the bolus is immediately seized and tightly held, and the muscular fibres contracting above it, while they are comparatively lax below, it is rapidly thrust into the œsophagus. By the muscular walls of this tube it is grasped and propelled onwards, in a similar fashion, until it reaches the stomach.

17. Drink is taken in exactly the same way. It does not fall down the pharynx and gullet, but each gulp is grasped and passed down. Hence it is that jugglers are able to drink standing upon their heads, and that a horse, or ox, drinks with its throat lower than its stomach, feats which would be impossible if fluid simply fell down the gullet into the gastric cavity.

During these processes of mastication, insalivation, and deglutition, what happens to the food is, first, that it is

reduced to a coarser or finer pulp; secondly, that any matters it carries in solution are still more diluted by the water of the saliva; thirdly, that any starch it may contain begins to be changed into sugar by the peculiar constituent (ptyalin) of the saliva.

18. The stomach, like the gullet, consists of a tube with muscular walls composed of smooth muscular fibres, and lined by an epithelium; but it differs from the gullet in several circumstances. In the first place, its cavity is greatly larger, and its left end is produced into an enlargement which, because it is on the heart side of the body, is called the *cardiac* dilatation (Fig. 42, *b*). The opening of the gullet into the stomach, termed the *cardiac aperture*, is consequently nearly in the middle of the whole length of the organ, which presents a long, convex, *greater curvature*, along its front or under edge, and a short, concave, *lesser curvature*, on its back or upper contour. Towards its right extremity the stomach narrows, and, where it passes into the intestine, the muscular fibres are so disposed as to form a sort of sphincter around the aperture of communication. This is called the *pylorus* (Fig. 42, *d*).

The mucous membrane lining the wall of the stomach contains, or rather is made up of, a multitude of small glands which open upon its surface. These are on the whole simple in nature, being long tubular glands, but they vary in character, their blind ends being more divided and twisted at one part of the stomach than another. Each gland is lined by an epithelium, the cells of (Fig. 43), which are of a peculiar nature and not all alike. It is these, called *gastric glands*, which, when food passes into the stomach, throw out a thin acid fluid, the *gastric juice*.

When the stomach is empty, its mucous membrane is pale and hardly more than moist. Its small arteries are then in a state of constriction, and comparatively little blood is sent through it. On the entrance of food a nervous action is set up, which causes these small arteries to dilate; the mucous membrane consequently receives a much larger quantity of blood, it becomes very red, little drops of fluid gather at the mouth of the glands, and finally run down as gastric juice. The process is very

similar to the combined blushing and sweating which takes place when the sympathetic in the neck is divided.

Pure gastric juice appears to consist of little more than water, containing a few saline matters in solution, and its acidity is due to the presence of free hydrochloric acid; it possesses, however, in addition a small quantity of a peculiar substance called *pepsin*, which is a body in many respects similar to, though very different in its effects from, *ptyalin* (§ 14).

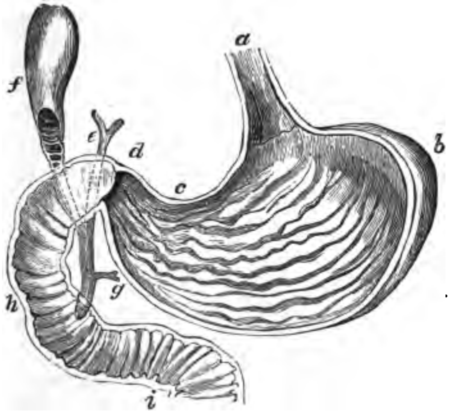


FIG. 42.—THE STOMACH LAID OPEN BEHIND.

a, the œsophagus; *b*, the cardiac dilatation; *c*, the lesser curvature; *d*, the pylorus; *e*, the biliary duct; *f*, the gall-bladder; *g*, the pancreatic duct, opening in common with the cystic duct opposite *h*; *h*, *i*, the duodenum.

Thus, when the food passes into the stomach, the contractions of that organ roll it about and mix it thoroughly with the gastric juice.

19. It is easy to ascertain the properties of gastric juice experimentally, by putting a small portion of the mucous membrane of a stomach into acidulated water containing small pieces of meat, hard-boiled egg, or other proteids, and keeping the mixture at a temperature of about 100°.

After a few hours it will be found that the white of egg, if not in too great quantity, has become dissolved: while all that remains of the meat is a pulp, consisting chiefly of the connective tissue and fatty matters which it contained. This is *artificial digestion*, and it has been proved by experiment that precisely the same operation takes place

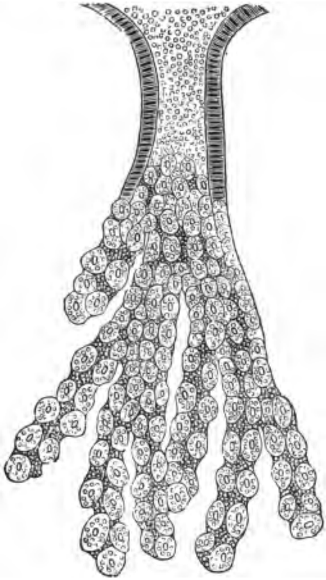


FIG. 43.

One of the glands which secrete the gastric juice, magnified about 350 diameters.

when food undergoes natural digestion within the stomach of a living animal.

Thus gastric juice dissolves proteids, and the proteid solution thus effected is called a *peptone*, and has pretty

much the same characters, whatever the nature of the proteid which has been digested.

Peptone differs from all other proteids in its extreme solubility, and in the readiness with which it passes through animal membranes. Many proteids, as fibrin, are naturally insoluble in water, and others, such as white of egg, though apparently soluble, are not completely so, and can be rendered quite solid or coagulated by being simply heated, as when an egg is boiled. A solution of peptone however is perfectly fluid, does not become solid, and is not at all coagulated by boiling. Again, if a quantity of albumin, such as white of egg or serum of blood, be tied up in a bladder, and the bladder immersed in water, very little of the proteid will pass through the bladder into the water, provided that there are no holes. If, however, peptone be used instead of albumin, a very large quantity will speedily pass through into the water, and a quantity of water will pass from the outside into the bladder, causing it to swell up. This process is called *osmosis*, and is evidently of great importance in the economy; and the purpose of the conversion of the various proteids by digestion into peptone seems to be, in part at least, to enable this class of food-stuff to pass readily into the blood through the thin partition formed by the walls of the mucous membrane of the intestine and the coats of the capillaries. Similarly, starch, even when boiled, and so partially dissolved, will not pass through membranes, whereas sugar does so with the greatest ease. Hence the reason of the conversion of starch, by digestion, into sugar.

It takes a very long time (some days) for the dilute acid alone to dissolve proteid matters, and hence the solvent power of gastric juice must be chiefly attributed to the pepsin.

As far as we know gastric juice has no direct action on fats; by breaking up, however, the proteid framework in which animal and vegetable fats are imbedded, it sets these free, and so helps their digestion by exposing them to the action of other agents. It appears, too, that gastric juice has no direct action on amyloids; on the contrary, the conversion of the starch into sugar begun in the mouth appears to be wholly or partially arrested by the

FIG. 44.—THE VISCERA OF A RABBIT AS SEEN UPON SIMPLY OPENING THE CAVITIES OF THE THORAX AND ABDOMEN WITHOUT ANY FURTHER DISSECTION.

A, cavity of the thorax, pleural cavity on either side; *B*, diaphragm;

acidity of the contents of the stomach, ptyalin being active only in an alkaline or neutral mixture.

20. By continual rolling about, with constant additions of gastric juice, the food becomes reduced to the consistence of pea-soup, and is called *chyme*. In this state it is, in part, allowed to escape through the pylorus and to enter the duodenum; but a great deal of the fluid (consisting of peptone together with any saccharine fluids resulting from the partial conversion of starch, or otherwise) is at once absorbed, making its way, by imbibition, through the walls of the delicate and numerous vessels of the stomach into the current of the blood, which is rushing though the gastric veins to the *vena portæ*.

21. The *intestines* form one long tube, with mucous and muscular coats, like the stomach; and, like it, they are enveloped in peritoneum. They are divided into two portions—the *small intestines* and the *large intestines*; the latter, though shorter, having a much greater diameter than the former. The name of *duodenum*, is given to that part of the small intestine which immediately succeeds the stomach, and is bent upon itself and fastened by the peritoneum against the back wall of the abdomen, in the loop shown in Fig. 42. It is in this loop that the head of the pancreas lies (Fig. 38).

The rest of the small intestines is no wider than the duodenum, so that the transition from the small intestine to the large (Fig. 45, *a*) is quite sudden. The opening of the small intestine into the large is provided with prominent lips which project into the cavity of the latter, and oppose the passage of matters from it into the small intestine, while they readily allow of a passage the other way. This is the *ileo-cæcal* valve (Fig. 45, *d*).

The large intestine forms a blind dilatation beyond the ileo-cæcal valve, which is called the *cæcum*; and from this an elongated, blind process is given off, which, from

C, ventricles of the heart; *D*, auricles; *E*, pulmonary artery; *F*, aorta; *G*, lungs collapsed, and occupying only back part of chest; *H*, lateral portions of pleural membranes; *I*, cartilage at the end of sternum (ensiform cartilage); *K*, portion of the wall of body left between thorax and abdomen: *a*, cut ends of the ribs; *L*, the liver, in this case lying more to the left than the right of the body; *M*, the stomach, a large part of the greater curvature being shown; *N*, duodenum; *O*, small intestine; *P*, the cæcum, so largely developed in this and other herbivorous animals; *Q*, the large intestine.

its shape, is called the *vermiform appendix* of the cæcum (Fig. 45, *b*).

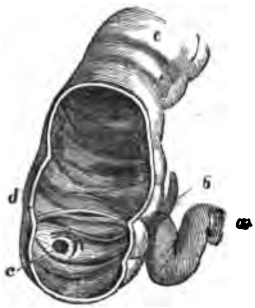


FIG. 45.

The termination of the illeum, *a*, in the cæcum, and the continuation of the latter into the colon, *c*; *d*, the ileo-cæcal valve; *e*, the aperture of the *appendix vermiformis* (*b*) into the cæcum.

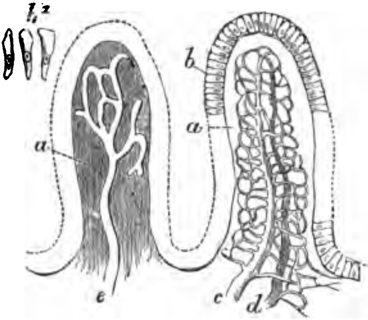


FIG. 46.—SEMI-DIAGRAMMATIC VIEW OF TWO VILLI OF THE SMALL INTESTINES. (Magnified about 50 diameters.)

a, substance of the villus; *b*, its epithelium, of which some cells are seen detached at b^1; *c d*, the artery and vein, with their connecting capillary network which envelopes and hides *e*, the lacteal radicle which occupies the centre of the villus and opens into a network of lacteal vessels at its base.

The cæcum lies in the lower part of the right side of the abdominal cavity. The *colon*, or first part of the large intestine, passes upwards from it as the *ascending colon;* then making a sudden turn at a right angle, it passes across to the left side of the body, being called the *transverse colon* in this part of its course; and next suddenly bending backwards along the left side of the abdomen, it becomes the *descending colon.* This reaches the middle line and becomes the *rectum*, which is that part of the large intestine which opens externally.

22. The mucous membrane of the whole intestine is provided with numerous small and simple glands (named after Lieberkühn), which pour into it a secretion, the *intestinal juice*, the precise functions of which are unknown, though possibly in some animals it may possess the power of converting starch into sugar, and proteids into peptone. At the commencement of the duodenum are certain racemose glands, called the glands of Brunner, whose function seems unimportant.

Structures peculiar to the small intestine are the *valvulæ conniventes*, transverse folds of the mucous membrane which increase the surface; and the *villi*, which are minute club-shaped processes of the mucous membrane set side by side, like the pile of velvet, over the whole inner surface of the small intestine. Each villus is a tongue-shaped projection of the mucous membrane and has a covering of epithelium; it contains in its interior the *lacteal radicle*, or commencement of a *lacteal vessel* (Lesson II. § 6), between which and the epithelium lies a capillary network with its afferent artery and efferent vein.

The intestines receive their blood almost directly from the aorta. Their veins carry the blood which has traversed the intestinal capillaries to the *vena portæ.*

The fibres of the muscular coat of the intestines (which lies between the mucous membrane and the serous, or peritoneal, investment) are disposed longitudinally and circularly; the longitudinal coat being much thinner than, and placed outside the circular coat. Now the circular fibres of any part contract, successively, in such a manner that the upper fibres, or those nearer the stomach, contract before the lower ones, or those nearer the large intestine.

It follows from this so-called *peristaltic contraction*, that the contents of the intestines are constantly being propelled, by successive and progressive narrowing of their calibre, from their upper towards their lower parts. And the same peristaltic movement goes on in the large intestine from the ileo-cæcal valve to the anus.

The large intestine presents noteworthy peculiarities in the arrangement of the longitudinal muscular fibres of the colon into three bands, which are shorter than the walls of the intestine itself, so that the latter is thrown into puckers and pouches; and in the disposition of muscular fibres around the termination of the rectum into a ring-like sphincter muscle, which keeps the aperture firmly closed, except when defæcation takes place.

23. The only secretions, besides those of the proper intestinal glands, which enter the intestine, are those of the liver and the pancreas—the *bile* and the *pancreatic juice*. The ducts of these organs have a common opening in the middle of the bend of the duodenum; and, since the common duct passes obliquely through the coats of the intestine, its walls serve as a kind of valve, obstructing the flow of the contents of the duodenum into the duct, but readily permitting the passage of bile and pancreatic juice into the duodenum (Figs. 36, 38, 42).

Pancreatic juice is an alkaline fluid not unlike saliva in many respects; it differs, however, in containing a considerable quantity of proteid material. Bile we have already studied.

After gastric digestion has been going on some time, and the semi-digested food begins to pass on into the duodenum, the pancreas comes into activity, its blood-vessels dilate, it becomes red and full of blood, its cells secrete rapidly, and a copious flow of pancreatic juice takes place along its duct into the intestine.

The secretion of bile by the liver is much more continuous than that of the pancreas, and is not so markedly increased by the presence of food in the stomach. There is, however, a store of bile laid up in the gall-bladder; and as the acid chyme passes into the duodenum, and flows over the common aperture of the gall and pancreatic ducts, a quantity of bile from this reservoir in the gall-bladder is ejected into the intestine.

The bile and pancreatic juice together here mix with the chyme and produce remarkable changes in it.

24. In the first place, the alkali of these juices neutralises the acid of the chyme; in the second place, both the bile and the pancreatic juice appear to exercise an influence over the fatty matters contained in the chyme, which facilitates the subdivision of these fats into very minute separate particles. The fat, as it passes from the stomach, is very imperfectly mixed with the other constituents of the chyme; and the drops of fat or oil (for all the fat of the food is melted by the heat of the stomach) readily run together into larger masses. By the combined action, however, of the bile and pancreatic juice the large drops of fat which pass into the intestine from the stomach are *emulsified*, that is to say are broken up into exceedingly minute particles, and thoroughly mixed with the rest of the contents; they are brought in fact to very much the same condition as that in which fat (*i.e.* butter) exists in milk. When this emulsifying has taken place the contents of the small intestine no larger appear grey like the chyme in the stomach but white and milky; in fact it and milk are white for the same reason, viz., on account of the multitude of minute suspended fatty particles reflecting a great amount of light.

The contents of the small intestine, thus white and milky, are sometimes called *chyle*; but it is best to reserve this name for the contents of the lacteals, of which we shall have to speak directly.

The emulsifying of the fats is not, however, the only change going on in the small intestine. The pancreatic juice has an action on starch similar to that of saliva, but much more powerful. During the short stay in the mouth very little starch has had time to be converted into sugar, and in the stomach, as we have seen, the action of the saliva is arrested. In the small intestine, however, the pancreatic juice takes up the work again; and indeed, by far the greater part of the starch which we eat is digested, that is, changed into sugar, by the action of this juice.

Nor is this all, for, in addition to the above, the alkaline pancreatic juice has a powerful effect on proteids very similar to that exerted by the acid gastric juice;

it converts them into peptones, and the peptones so produced do not differ materially from the peptones resulting from gastric digestion.

Hence it appears that, while in the mouth amyloids only, and in the stomach proteids only, are digested, in the intestine all three kinds of food-stuffs, proteids, fats, and amyloids, are either completely dissolved or minutely subdivided, and so prepared for their passage into the vessels.

As the food is thrust along the small intestines by the grasping action of the peristaltic contractions, the digested matter which it contains is absorbed, that is, passes away from the interior of the intestine into the blood vessels and lacteals lying in the intestinal walls.

A great deal of this absorption takes place in the small intestine (though the process is continued on in the large intestine), and there can be no doubt that it is largely effected by means of the villi. Each villus as we have seen (§ 22), is covered by a layer of epithelium, and contains in the centre a lacteal radicle, between which and the epithelium lies a network of capillary blood-vessels embedded in a delicate tissue. Now in some way or other, not even yet thoroughly understood, the majority of the minute particles of the finely divided, emulsified fat, pass through the epithelium, past the capillary blood-vessels, into the central lacteal radicle; so that, after a fatty meal, these lacteal radicles of the villi become filled with fat. The lacteal radicle is continuous with the interior of the lymphatic vessels which ramify in the walls of the intestine, and which pass into the larger lymphatic vessels running along the mesentery towards the thoracic duct. Into these vessels the finely divided fat passes from the lacteal radicle of the villus, and, mixing with the ordinary lymph contained in these vessels, gives their contents a white, milky appearance. Lymph thus white and milky from the admixture of a large quantity of finely divided fat is called chyle; and this white chyle may after a meal be traced along the lymphatics of the mesentery to the thoracic duct, and along the whole course of that vessel to its junction with the venous system. After a meal, in fact, this vessel is continually pouring into the blood a large quantity of chyle, *i.e.* of lymph made white

and milky by the admixture of fats drawn from the villi of the small intestine.

The peptones and sugar, being soluble and diffusible, pass, by a process which may be broadly described as osmosis, through the epithelium into the substance of the villi, and here they appear to be taken up by the capillary blood-vessels of the villus, so that very little if any of them gets to the lacteal radicle. From the capillaries of the villi the peptones and sugar are then carried along the *vena portæ* to the liver, where they probably undergo some further change. So that while the fat, though it gets for the most part into the general blood current by a roundabout way, viz., by the lymphatics, reaches the blood, as far as we know, very little changed, the peptones and sugars on the other hand, though also taking a roundabout course, viz., by the liver, are probably altered before they are thrown into the general blood stream; for the portal blood in which they are carried is acted upon by the liver before it flows through the hepatic vein into the general venous system. But concerning both the process of absorption itself and the changes undergone by the absorbed products before they reach the heart, ready to be distributed all over the body, we have probably much yet to learn.

25. As the food thus passes along the small intestine, digestion and absorption go on hand in hand. All the way down, the proteids, amyloids, and fats of a meal are being dissolved or freely divided, or otherwise changed, and passing away into the lacteals or blood-vessels. So that, by the time the contents of the intestine have reached the ileo-cæcal valve, a great deal of the nutritious matter has been removed. Still, even in the large intestine, some nutritious matter has still to be acted upon; and we find that, in the cæcum and commencement of the large intestine, changes are taking place, apparently somewhat of the nature of fermentation, whereby the contents become acid. In herbivorous animals it is probable that very considerable changes are effected in this part of the alimentary canal.

One marked feature of the changes undergone in the large intestine is the rapid absorption of water. Whereas in the small intestine, the amount of fluid secreted into

the canal about equals that which is removed by absorption, so that the contents at the ileo-cæcal valve are about as fluid as they are in the duodenum ; in the large intestine on the contrary, especially in its later portions, the contents become less and fluid. At the same time a characteristic odour and colour are developed, and the remains of the food, now consisting either of undigestible material, or of material which has escaped the action of the several digestive juices, or withstood their influence, gradually assume the characters of fæces.

LESSON VII.

MOTION AND LOCOMOTION.

1. IN the preceding Lessons the manner in which the incomings of the human body are converted into its outgoings has been explained. It has been seen that new matter, in the form of vital and mineral food, is constantly appropriated by the body, to make up for the loss of old matter, which is as constantly going on in the shape, chiefly, of carbonic acid, urea, and water.

The vital foods are derived directly, or indirectly, from the vegetable world: and the products of waste either are such compounds as abound in the mineral world, or immediately decompose into them. Consequently, the human body is the centre of a stream of matter which sets incessantly from the vegetable and mineral worlds into the mineral world again. It may be compared to an eddy in a river, which may retain its shape for an indefinite length of time, though no one particle of the water of the stream remains in it for more than a brief period.

But there is this peculiarity about the human eddy, that a large portion of the particles of matter which flow into it have a much more complex composition than the particles which flow out of it. To speak in what is not altogether a metaphor, the atoms enter the body for the most part, piled up into large heaps, and tumble down into small heaps before they leave it. The energy which

they set free in thus tumbling down, is the source of the active powers of the organism.

2. These active powers are chiefly manifested in the form of motion—movement, that is, either of part of the body, or of the body as a whole, which last is termed *locomotion.*

The organs which produce total or partial movements of the human body are of three kinds: *cells exhibiting amœboid movements*, *cilia*, and *muscles.*

The *amœboid movements* of the white corpuscles of the blood have been already described, and it is probable that similar movements are performed by many other simple cells of the body in various regions.

The amount of movement to which each cell is thus capable of giving rise may appear perfectly insignificant; nevertheless, there are reasons for thinking that these amœboid movements are of great importance to the economy, and may under certain circumstances be followed by very notable consequences.

3. *Cilia* are filaments of extremely small size, attached by their bases to, and indeed growing out from, the free surfaces of certain epithelial cells (see Lesson XII.); there being in most instances very many (thirty for instance), but, in some cases, only a few cilia on each cell. In some of the lower animals, cells may be found possessing only a single cilium. They are in incessant waving motion, so long as life persists in them. Their most common form of movement is that each cilium is suddenly bent upon itself, becomes sickle-shaped instead of straight, and then more slowly straightens again, both movements, however, being extremely rapid and repeated about ten times or more every second. These two movements are of course antagonistic; the bending drives the water or fluid in which the cilium is placed in one direction, while the straightening drives it back again. Inasmuch, however, as the bending is much more rapid than the straightening, the force expended on the water in the former movement is greater than in the latter. The total effect of the double movement therefore is to drive the fluid in the direction towards which the cilium is bent; that is, of course, if the cell on which the cilia are placed is fixed. If the cell be floating free, the effect is to drive or row the cell backwards; for

the cilia may continue their movements even for some time after the epithelial cell, with which they are connected, is detached from the body. And not only do the movements of the cilia thus go on independently of the rest of the body, but they appear not to be controlled by the action of the nervous system. Each cilium is comparable to one of the mobile processes of a white corpuscle. A ciliated cell differs from an amœboid cell in that its contractile processes are permanent, have a definite shape, and are localised in a particular part of the cell, and that the movements of the processes are performed rhythmically and always in the same way. But the exact manner in which the movement of a cilium is brought about is not as yet thoroughly understood.

Although no other part of the body has any control over the cilia, and though, so far as we know, they have no direct communication with one another, yet their action is directed towards a common end—the cilia, which cover extensive surfaces, all working in such a manner as to sweep whatever lies upon that surface in one and the same direction. Thus, the cilia which are developed upon the epithelial cells, which line the greater part of the nasal cavities and the trachea, with its ramifications, tend to drive the mucus in which they work, outwards.

In addition to the air-passages, cilia are found, in the human body, in a few other localities; but the part which they play in man is insignificant in comparison with their function in the lower animals, among many of which they become the chief organs of locomotion.

4. *Muscles* (Lesson I. § 13) are accumulations of fibres, each fibre having a definite structure which is different in the *striated* and *unstriated* kinds (see Lesson XII.). These fibres are bound up into small bundles by fibrous (or connective) tissue, which carries the vessels and nerves; and these bundles are again similarly bound up together in various ways so as to form muscles of various shapes and sizes. Every fibre has the property, under certain conditions, of shortening in length, while it increases its other dimensions, so that the absolute volume of the fibre remains unchanged. This property is called *muscular contractility;* and whenever, in virtue of this property, a muscular fibre *contracts*, it tends to bring

its two ends, with whatever may be fastened to them, together.

The condition which ordinarily determines the contraction of a muscular fibre is, as we have seen (Lesson V. § 31), the passage along the nerve fibre, which is in close anatomical connection with the muscular fibre, of a ***nervous impulse***, *i.e.* of a particular change in the substance of the nerve which is propagated from particle to particle along the fibre. The nerve fibre is thence called a ***motor*** fibre, because, by its influence on a muscle, it becomes the indirect means of producing motion (Lesson XI. § 6).

Muscle is a highly elastic substance, It contains a large amount of water (about as much as the blood), and during life has a clear and semi-transparent aspect.

When subjected to pressure in the perfectly fresh state, and after due precautions have been taken to remove all the contained blood, *striated* muscle (Lesson XII. § 15) yields a fluid which undergoes spontaneous coagulation at ordinary temperatures. At a longer or shorter time after death this coagulation takes place within the muscles themselves. They become more or less opaque, and, losing their previous elasticity, set into hard, rigid masses, which retain the form which they possess when the coagulation commences, Hence the limbs become fixed in the position in which death found them, and the body passes into the condition of what is termed the "death-stiffening," or *rigor mortis*. This stiffening is accompanied by a change in the chemical reaction of the muscle, for while living muscle, when tested with litmus is faintly alkaline or neutral, at least when at rest, it becomes distinctly acid as *rigor mortis* sets in. And it is a curious fact that a similar acidity is developed even in a living muscle, when it contracts.

After the lapse of a certain time the coagulated matter liquefies, and the muscles pass into a loose and flaccid condition, which marks the commencement of putrefaction.

It has been observed that the sooner *rigor mortis* sets in, the sooner it is over; and the later it commences, the longer it lasts. The greater the amount of muscular exertion and consequent exhaustion before death, the sooner *rigor mortis* sets in.

Rigor mortis evidently presents some analogies with the coagulation of the blood, and the substance which thus coagulates within the fibre (*myosin* (or muscle-clot) as it is sometimes called) is in many respects not unlike fibrin. It forms at least the greater part of the substance which may be extracted from dead muscle by dilute acids, and which is called *syntonin* (see Lesson VI. § 4). Besides myosin, muscle contains other varieties of proteid material about which we at present know little; a variable quantity of fat; certain inorganic saline matters, phosphates and potash being, as is the case in the red blood-corpuscles, in excess; and a large number of substances existing in small quantities, and often classed together as 'extractives.' Some of these extractives contain nitrogen; the most important of this class is *kreatin*, a crystalline body which is supposed to be the chief form in which nitrogenous waste matter leaves the muscle on its way to become urea.

The other class of extractives contains bodies free from nitrogen, perhaps the most important of which are *lactic acid* and glycogen.

Most muscles are of a deep, red colour; this is due in part to the blood remaining in their vessels; but only in part, for each fibre (into which no capillary enters) has a reddish colour of its own, like a blood-corpuscle but fainter. And this colour is probably due to the fibre possessing a small quantity of that same hæmoglobin in which the blood-corpuscles are so rich.

5. Muscles may be conveniently divided into two groups, according to the manner in which the ends of their fibres are fastened; into muscles not attached to solid levers, and muscles attached to solid levers.

Muscles not attached to solid levers.—Under this head come the muscles which are appropriately called *hollow* muscles, inasmuch as they inclose a cavity or surround a space; and their contraction lessens the capacity of that cavity, or the extent of that space.

The muscular fibres of the heart, of the blood-vessels, of the lymphatic vessels, of the alimentary canal, of the urinary bladder, of the ducts of the glands, of the iris of the eye, are so arranged as to form hollow muscles.

In the heart the muscular fibres which, though peculiar

are striated, are arranged in an exceedingly complex manner round the several cavities, and they contract, as we have seen, in a definite order.

The iris of the eye is like a curtain, in the middle of which is a circular hole. The muscular fibres are of the smooth or unstriated kind (see Lesson XII.), and they are disposed in two sets: one set radiating from the edges of the hole to the circumference of the curtain; and the other set arranged in circles, concentrically with the aperture. The muscular fibres of each set contract suddenly and together, the radiating fibres necessarily enlarging the hole, the circular fibres diminishing it.

In the alimentary canal the muscular fibres are also of the unstriated kind, and they are disposed in two layers; one set of fibres being arranged parallel with the length of the intestines, while the others are disposed circularly, or at right angles to the former.

As has been stated above (Lesson VI. § 22), the contraction of these muscular fibres is successive; that is to say, all the muscular fibres, in a given length of the intestines, do not contract at once, but those at one end contract first, and the others follow them until the whole series have contracted. As the order of contraction is, naturally, always the same, from the upper towards the lower end, the effect of this peristaltic contraction is, as we have seen, to force any matter contained in the alimentary canal, from its upper towards its lower extremity. The muscles of the walls of the ducts of the glands have a substantially similar arrangement. In these cases the contraction of each fibre is less sudden and lasts longer than in the case of the heart.

6. *Muscles attached to definite levers.*—The great majority of the muscles in the body are attached to distinct levers, formed by the bones, the minute structure of which is explained in Lesson XII. § 11. In such bones as are ordinarily employed as levers, the osseous tissue is arranged in the form of a *shaft* (Fig. 47, *b*), formed of a very dense and compact osseous matter, but often containing a great central cavity (*b*) which is filled with a very delicate vascular and fibrous tissue loaded with fat called *marrow*. Towards the two ends of the bone, the compact matter of the shaft thins out, and is replaced by a much

thicker but looser sponge-work of bony plates and fibres, which is termed the *cancellous* tissue of the bone. The

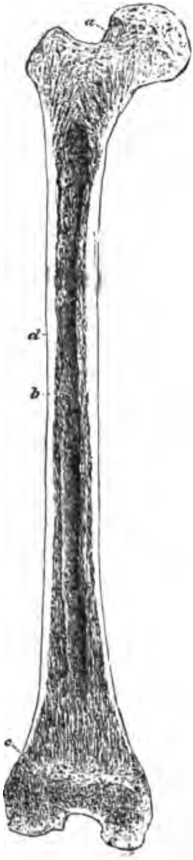


FIG. 47.—LONGITUDINAL SECTION OF THE SHAFT OF A HUMAN FEMUR OR THIGH-BONE.

a, the head, which articulates with the haunch-bone; *b*, the medullary cavity, and *d*, the dense bony substance of the shaft; *c*, the part which enters into the knee-joint, articulating with the shin-bone, or tibia.

surface even of this part, however, is still formed by a thin sheet of denser bone.

At least one end of each of these bony levers is fashioned into a smooth, articular surface, covered with cartilage, which enables the relatively fixed end of the bone to play upon the corresponding surface of some other bone with which it is said to be *articulated* (see § 11), or, contrariwise, allows that other bone to move upon it.

It is one or other of these extremities which plays the part of fulcrum when the bone is in use as a lever.

Thus, in the accompanying figure (Fig. 48) of the bones of the upper extremity, with the attachments of the *biceps*

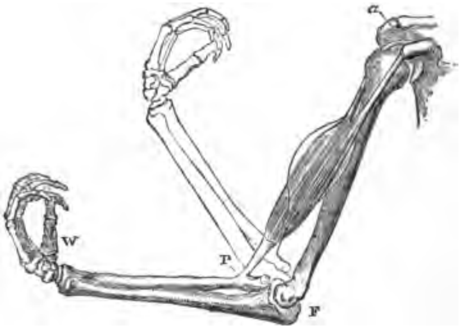


FIG. 48.—THE BONES OF THE UPPER EXTREMITY WITH THE BICEPS MUSCLE.

The two tendons by which this muscle is attached to the scapula are seen at *a*. P, indicates the attachment of the muscle to the radius, and hence the point of action of the power; F, the fulcrum, the lower end of the humerus on which the upper end of the radius (together with the ulna) moves; W, the weight (of the hand).

muscle to the shoulder-blade and to one of the two bones of the fore-arm called the *radius*, P indicates the point of action of the power (the contracting muscle) upon the radius.

But to understand the action of the bones, as levers, properly, it is necessary to possess a knowledge of the different kinds of levers and be able to refer the various

combinations of the bones to their appropriate lever-classes.

A lever is a rigid bar, one part of which is absolutely or relatively fixed, while the rest is free to move. Some one point of the moveable part of the lever is set in motion by a force, in order to communicate more or less of that motion to another point of the moveable part, which presents a resistance to motion in the shape of a weight or other obstacle.

Three kinds of levers are enumerated by mechanicians, the definition of each kind depending upon the relative positions of the point of support, or *fulcrum;* of the point

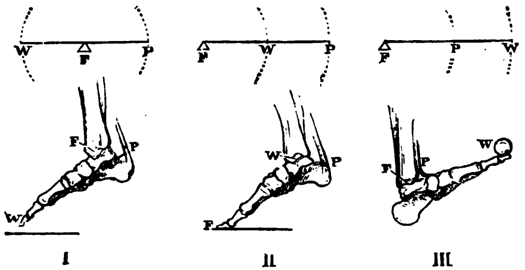


FIG. 49.

The upper three figures represent the three kinds of levers; the lower, the foot, when it takes the character of each kind.—W, weight or resistance; F, fulcrum; P, power.

which bears the *resistance, weight,* or other obstacle to be overcome by the force; and of the point to which the force, or *power* employed to overcome the obstacle, is applied.

If the fulcrum be placed between the power and the weight, so that, when the power sets the lever in motion, the weight and the power describe arcs, the concavities of which are turned towards one another, the lever is said to be of the *first order.* (Fig. 49, I.)

If the fulcrum be at one end, and the weight be between it and the power, so that weight and power describe concentric arcs, the weight moving through the less space

when the lever moves, the lever is said to be of the *second order.* (Fig. 49, II.)

And if, the fulcrum being still at one end, the power be between the weight and it, so that, as in the former case, the power and weight describe concentric arcs, but the power moves through the less space, the lever is of the *third order.* (Fig. 49, III.)

7. In the human body, the following parts present examples of levers of the first order.

(*a*) The skull in its movements upon the atlas, as *fulcrum.*

(*b*) The pelvis in its movements upon the heads of the thigh-bones, as *fulcrum.*

(*c*) The foot, when it is raised, and the toe tapped on the ground, the ankle-joint being *fulcrum.* (Fig. 49, I.)

The positions of the weight and of power are not given in either of these cases, because they are reversed according to circumstances. Thus, when the face is being depressed, the power is applied in front, and the weight to the back part, of the skull; but when the face is being raised, the power is behind and the weight in front. The like is true of the pelvis, according as the body is bent forward, or backward, upon the legs. Finally, when the toes, in the action of tapping, strike the ground, the power is at the heel, and the resistance in the front of the foot. But when the toes are raised to repeat the act, the power is in front, and the weight, or resistance, is at the heel, being, in fact, the inertia and elasticity of the muscles and other parts of the back of the leg.

But in all these cases, the lever remains one of the first class, because the fulcrum, or fixed point on which the lever turns, remains between the power and the weight, or resistance.

8. The following are three examples of levers of the second order:—

(*a*) The thigh-bone of the leg which is bent up towards the body and not used, in the action of hopping.

For, in this case, the fulcrum is at the hip-joint. The power (which may be assumed to be furnished by the thick muscle[1] of the front of the thigh) acts upon the knee-cap;

[1] This muscle, called *rectus*, is attached above to the haunch-bone and below to the knee-cap (Fig. 2, 2, p. 12). The latter bone is connected by a strong ligament with the *tibia.*

and the position of the weight is represented by that of the centre of gravity of the thigh and leg, which will lie somewhere between the end of the knee and the hip.

(*b*) A rib when depressed by the *rectus* muscle[1] of the abdomen, in expiration.

Here the fulcrum lies where the rib is articulated with the spine; the power is at the sternum—virtually the opposite end of the rib; and the resistance to be overcome lies between the two.

(*c*) The raising of the body upon the toes, in standing on tiptoe, and in the first stage of making a step forwards. (Fig. 49, II.)

Here the fulcrum is the ground on which the toes rest; the power is applied by the muscles of the calf to the heel (Fig. 2, I.); the resistance is so much of the weight of the body as is borne by the ankle-joint of the foot, which of course lies between the heel and the toes.

9. Three examples of levers of the third order are—

(*a*) The spine, head, and pelvis, considered as a rigid bar, which has to be kept erect upon the hip-joints. (Fig. 2.)

Here the fulcrum lies in the hip-joints, the weight is high above the fulcrum, at the centre of gravity of the head and trunk; the power is supplied by the extensor muscles (Fig. 2, 2) in the front of, or the flexor muscles (Fig. 2, II.) at the back of, the thigh, and acts upon points comparatively close to the fulcrum.

(*b*) Flexion of the forearm upon the arm by the *biceps* muscle, when a weight is held in the hand.

In this case, the weight being in the hand and the fulcrum at the elbow-joint, the power is applied at the point of attachment of the tendon of the biceps, close to the latter. (Fig. 48.)

(*c*) Extension of the leg on the thigh at the knee-joint.

Here the fulcrum is the knee-joint; the weight is at the centre of gravity of the leg and foot, somewhere between the knee and the foot; the power is applied by the muscles in front of the thigh (Fig. 2, 2) through the ligament of the knee-cap, or *patella*, to the tibia, close to the knee-joint.

[1] This muscle lies in the front abdominal wall on each side of the middle line. It is attached to the sternum above and to the front of the pelvis below (Fig. 2, 3).

10. In studying the mechanism of the body, it is very important to recollect that one and the same part of the body may represent each of the three kinds of levers, according to circumstances. Thus it has been seen that the foot may, under some circumstances, represent a lever of the first, in others, of the second, order. But it may become a lever of the third order, as when one dances a weight resting upon the toes, up and down, by moving only the foot. In this case, the fulcrum is at the ankle-joint, the weight is at the toes, and the power is furnished by the extensor muscles at the front of the leg (Fig. 2, 1), which are inserted between the fulcrum and the weight. (Fig. 49, III.)

11. It is very important that the levers of the body should not slip, or work unevenly, when their movements are extensive, and to this end they are connected together in such a manner as to form strong and definitely-arranged *joints* or *articulations*.

Joints may be classified into imperfect and perfect.

(*a*) *Imperfect joints* are those in which the conjoined levers (bones or cartilages) present no smooth surfaces, capable of rotatory motion, to one another, but are connected by continuous cartilages, or ligaments, and have only so much mobility as is permitted by the flexibility of the joining substance.

Examples of such joints as these are to be met with in the vertebral column—the flat surfaces of the bodies of the vertebræ being connected together by thick plates of very elastic fibro-cartilage, which confer upon the whole column considerable play and springiness, and yet prevent any great amount of motion between the several vertebræ. In the pelvis (see Plate, Fig. VI.), the pubic bones are united to each other in front, and the iliac bones to the sacrum behind, by fibrous or cartilaginous tissue, which allows of only a slight play, and so gives the pelvis a little more elasticity than it would have if it were all one bone.

(*b*) In all *perfect joints*, the opposed bony surfaces which move upon one another are covered with cartilage, and between them is placed a sort of sac, which lines these cartilages, and, to a certain extent, forms the side walls of the joint; and which, secreting a small quantity of

viscid, lubricating fluid—the *synovia*—is called a *synovial membrane.*

12. The opposed surfaces of these *articular* cartilages, as they are called, may be spheroidal, cylindrical, or pulley-shaped; and the convexities of the one answer, more or less completely, to the concavities of the other.

Sometimes, the two articular cartilages do not come directly into contact, but are separated by independent plates of cartilage, which are termed *inter-articular.* The opposite faces of these inter-articular cartilages are fitted to receive the faces of the proper articular cartilages.

While these co-adapted surfaces and synovial membranes provide for the free mobility of the bones entering into a joint, the nature and extent of their motion is defined, partly by the forms of the articular surfaces, and partly by the disposition of the *ligaments*, or firm, fibrous cords which pass from one bone to the other.

13. As respects the nature of the articular surfaces, joints may be what are called *ball and socket joints*, when the spheroidal surface furnished by one bone plays in a cup furnished by another. In this case the motion of the former bone may take place in any direction, but the extent of the motion depends upon the shape of the cup—being very great when the cup is shallow, and small in proportion as it is deep. The shoulder is an example of a ball and socket joint with a shallow cup; the hip, of such a joint with a deep cup (Fig. 50).

14. *Hinge-joints* are single or double. In the former case, the nearly cylindrical head of one bone fits into a corresponding socket of the other. In this form of hinge-joint the only motion possible is in the direction of a plane perpendicular to the axis of the cylinder, just as a door can only be made to move round an axis passing through its hinges. The elbow is the best example of this joint in the human body, but the movement here is limited, because the *olecranon*, or part of the ulna which rises up behind the humerus, prevents the arm being carried back behind the straight line; the arm can thus be bent to, or straightened, but not bent back (Fig. 51). The knee and ankle present less perfect specimens of a single hinge-joint.

A double hinge-joint is one in which the articular sur-

face of each bone is concave in one direction, and convex in another, at right angles to the former. A man seated in a saddle is "articulated" with the saddle by such a joint. For the saddle is concave from before backwards,

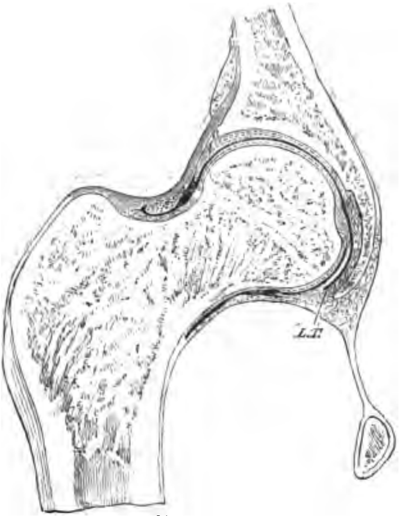


FIG. 50.—A SECTION OF THE HIP-JOINT TAKEN THROUGH THE ACETABULUM OR ARTICULAR CUP OF THE PELVIS AND THE MIDDLE OF THE HEAD AND NECK OF THE THIGH-BONE.

L.T. Ligamentum teres, or round ligament. The spaces marked with an interrupted line (- - - -) represent the articular cartilages. The cavity of the synovial membrane is indicated by the dark line between these, and, as is shown, extends along the neck of the femur beyond the limits of the cartilage. The peculiar shape of the pelvis causes the section to have the remarkable outline shown in the cut. This will be intelligible if compared with Fig. VI. in the plate.

and convex from side to side, while the man presents to it the concavity of his legs astride, from side to side, and the convexity of his seat, from before backwards.

The metacarpal bone of the thumb is articulated with

the bone of the wrist, called *trapezium*, by a double hinge-joint.

15. A *pivot-joint* is one in which one bone furnishes an axis, or pivot, on which another turns; or itself turns on its own axis, resting on another bone. A remarkable example of the former arrangement is afforded by the *atlas* and *axis*, or two uppermost vertebræ of the neck

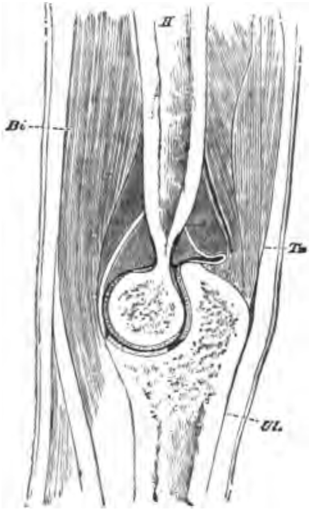


FIG. 51.—LONGITUDINAL AND VERTICAL SECTION THROUGH THE ELBOW-JOINT.

H, humerus; *Ul*, ulna, *Tr*, the *triceps* muscle, which extends the arm; *Bi*, the *biceps* muscle, which flexes it.

(Fig. 52). The axis possesses a vertical peg, the so-called *odontoid* process (*b*), and at the base of the peg are two, obliquely placed, articular surfaces (*a*). The atlas is a ring-like bone, with a massive thickening on each side. The inner side of the front of the ring plays round the neck of the odontoid peg, and the under surfaces of the

lateral masses glide over the articular faces on each side of the base of the peg. A strong ligament passes between the inner sides of the two lateral masses of the atlas, and keeps the hinder side of the neck of the odontoid peg in its place (Fig. 52, A). By this arrangement, the atlas is enabled to rotate through a considerable angle either way upon the axis, without any danger of falling forwards or backwards—accidents which would immediately destroy life by crushing the spinal marrow.

The lateral masses of the atlas have, on their upper faces, concavities (Fig. 52, A, *a*) into which the two convex, occipital condyles of the skull fit, and in which they play upward and downward. Thus the nodding of the

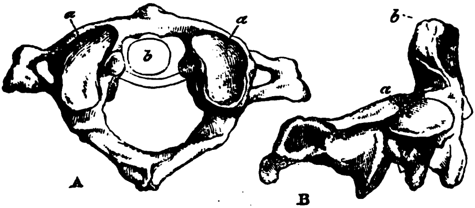


FIG. 52.

A. The atlas viewed from above; *a a*, upper articular surfaces of its lateral masses for the condyles of the skull; *b*, the peg of the axis vertebra.
B. Side view of the axis vertebra; *a*, articular surface for the lateral mass of the atlas; *b*, peg or odontoid process.

head is effected by the movement of the skull upon the atlas; while, in turning the head from side to side, the skull does not move upon the atlas, but the atlas slides round the odontoid peg of the axis vertebra.

The second kind of pivot-joint is seen in the forearm.

If the elbow and forearm, as far as the wrist, are made to rest upon a table, and the elbow is kept firmly fixed, the hand can nevertheless be freely rotated so that either the palm, or the back, is turned directly upwards. When the palm is turned upwards, the attitude is called *supination* (Fig. 53, A); when the back, *pronation* (Fig. 53, B).

The forearm is composed of two bones; one, the *ulna*, which articulates with the *humerus* at the elbow by the

hinge-joint already described, in such a manner that it can move only in flexion and extension (see § 17), and has no power of rotation. Hence, when the elbow and wrist are rested on a table, this bone remains unmoved.

But the other bone of the forearm, the *radius*, has its small upper end shaped like a very shallow cup with thick

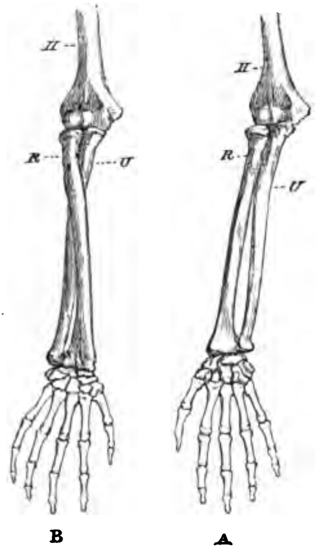


FIG. 53.
The bones of the right forearm in supination (A) and pronation (B).
H, humerus; *R*, radius; *U*, ulna.

edges. The hollow of the cup articulates with a spheroidal surface furnished by the humerus: the lip of the cup, with a concave depression on the side of the ulna.

The large lower end of the radius bears the hand, and has, on the side next the ulna, a concave surface, which articulates with the convex side of the small lower end of that bone.

Thus the upper end of the radius turns on the double surface, furnished to it by the pivot-like ball of the humerus, and the partial cup of the ulna; while the lower end of the radius can rotate round the surface furnished to it by the lower end of the ulna.

In *supination*, the radius lies parallel with the ulna, with its lower end to the outer side of the ulna (Fig. 53, A). In *pronation*, it is made to turn on its own axis above, and round the ulna below, until its lower half crosses the ulna, and its lower end lies on the inner side of the ulna (Fig. 53, B).

16. The ligaments which keep the mobile surfaces of bones together are, in the case of ball and socket joints, strong fibrous *capsules* which surround the joint on all sides. In hinge-joints, on the other hand, the ligamentous tissue is chiefly accumulated, in the form of *lateral ligaments*, at the sides of the joints. In some cases ligaments are placed within the joints, as in the knee, where the bundles of fibres which cross obliquely between the femur and the tibia are called *crucial* ligaments; or, as in the hip, where the *round ligament* passes from the bottom of the socket, or acetabulum of the pelvis to the ball furnished by the head of the femur (Fig. 50).

Again, two ligaments pass from the apex of the odontoid peg to both sides of the margin of the occipital foramen, *i.e.* the large hole in the base of the skull, through which the spinal cord passes to join the brain; these, from their function in helping to stop excessive rotation of the skull, are called *check ligaments* (Fig. 54, *a*).

In one joint of the body, the hip, the socket or *acetabulum* (Fig. 50) fits so closely to the head of the femur, and the capsular ligament so completely closes its cavity on all sides, that the pressure of the air must be reckoned among the causes which prevent dislocation. This has been proved experimentally by boring a hole through the floor of the acetabulum, so as to admit air into its cavity, when the thigh-bone at once falls as far as the round and capsular ligaments will permit it to do, showing that it was previously pushed close up by the pressure of the external air.

17. The different kinds of movement which the levers thus connected are capable of performing are called

flexion and *extension*; *abduction* and *adduction*; *rotation* and *circumduction*.

A limb is *flexed*, when it is bent; *extended*, when it is straightened out. It is *abducted*, when it is drawn away from the middle line; *adducted*, when it is brought to the middle line. It is *rotated*, when it is made to turn on its own axis; *circumducted*, when it is made to describe a conical surface by rotation round an imaginary axis.

No part of the body is capable of perfect rotation like a wheel, for the simple reason that such motion would

FIG. 54.

The vertebral column in the upper part of the neck laid open to show, *a*, the check ligaments of the axis; *b*, the broad ligament which extends from the front margin of the occipital foramen along the hinder faces of the bodies of the vertebræ; it is cut through, and the cut ends turned back to show, *c*, the special ligament which connects the point of the "odontoid" peg with the front margin of the occipital foramen; *I*, the atlas; *II*, the axis.

necessarily tear all the vessels, nerves, muscles, &c., which unite it with other parts.

18. Any two bones united by a joint may be moved one upon another in, at fewest, two different directions. In the case of a pure hinge-joint, these directions must be opposite and in the same plane; but, in all other joints, the movements may be in several directions and in various planes.

In the case of a pure hinge-joint, the two practicable movements—viz. flexion and extension—may be effected by means of two muscles, one for each movement, and running from one bone to the other, but on opposite sides of the joint. When either of these muscles contracts, it will pull its attached ends together, and bend or straighten, as the case may be, the joint towards the side on which it is placed. Thus the biceps muscle is attached, at one end, to the shoulder-blade, while, at the other end, its tendon passes in front of the elbow-joint to the radius (Figs. 48 and 51, *Bi*): when this muscle contracts, therefore, it bends, or flexes, the forearm on the arm. At the back of the joint there is the triceps (*Tr*, Fig. 51): when this contracts, it straightens, or extends, the forearm on the arm.

In the other extreme form of articulation—the ball and socket joint—movement in any number of planes may be effected, by attaching muscles in corresponding number and direction, on the one hand, to the bone which affords the socket, and on the other to that which furnishes the head. Circumduction will be effected by the combined and successive contraction of these muscles.

19. It usually happens that the bone to which one end of a muscle is attached is absolutely or relatively stationary, while that to which the other is fixed is movable. In this case, the attachment to the stationary bone is termed the *origin*, that to the movable bone the *insertion*, of the muscle.

The fibres of muscles are sometimes fixed directly into the parts which serve as their origins and insertions; but, more commonly, strong cords or bands of fibrous tissue, called *tendons*, are interposed between the muscle proper and its place of origin or insertion. When the tendons play over hard surfaces, it is usual for them to be separated from these surfaces by sacs containing fluid, which are called *bursæ;* or even to be invested by synovial sheaths, *i.e.* quite covered for some distance by a synovial bag forming a double sheath, very much in the same way that the bag of the pleura covers the lung and the chest-wall.

Usually, the direction of the axis of a muscle is that of a straight line joining its origin and its insertion. But in some muscles, as the *superior oblique muscle* of the eye, the tendon passes over a pulley formed by ligament, and

completely changes its direction before reaching its insertion. (See Lesson IX.)

Again, there are muscles which are fleshy at each end, and have a tendon in the middle. Such muscles are called *digastric*, or two-bellied. In the curious muscle which pulls down the lower jaw, and especially receives this name of *digastric*, the middle tendon runs through a pulley connected with the hyoid bone; and the muscle, which passes downwards and forwards from the skull to this pulley, after traversing it, runs upwards and forwards to the lower jaw (Fig. 55).

20. We may now pass from the consideration of the mechanism of mere motion to that of locomotion.

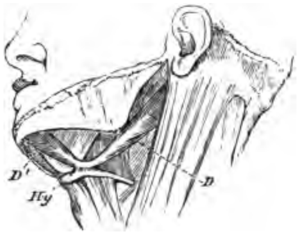


FIG. 55.—THE COURSE OF THE DIGASTRIC MUSCLE.

D, its posterior belly; D′, its anterior belly; between the two is the tendon passing through its pulley connected with *Hy*, the hyoid bone.

When a man who is standing erect on both feet proceeds to *walk*, beginning with the right leg, the body is inclined, so as to throw the centre of gravity forward; and, the right foot being raised, the right leg is advanced for the length of a step, and the foot is put down again. In the meanwhile, the left heel is raised, but the toes of the left foot have not left the ground when the right foot has reached it, so that there is no moment at which both feet are off the ground. For an instant, the legs form two sides of an equilateral triangle, and the centre of the body is consequently lower than it was when the legs were parallel and close together.

The left foot, however, has not been merely dragged away from its first position, but the muscles of the calf, having come into play, act upon the foot as a lever of the second order, and thrust the body, the weight of which rests largely on the left astragalus, upwards, forwards, and to the right side. The momentum thus communicated to the body causes it, with the whole right leg, to describe an arc over the right astragalus, on which that leg rests below. The centre of the body consequently rises to its former height as the right leg becomes vertical, and descends again as the right leg, in its turn, inclines forward.

When the left foot has left the ground, the body is supported on the right leg, and is well in advance of the left foot; so that, without any further muscular exertion, the left foot swings forward like a pendulum, and is carried by its own momentum beyond the right foot, to the position in which it completes the second step.

When the intervals of the steps are so timed that each swinging leg comes forward into position for a new step without any exertion on the part of the walker, walking is effected with the greatest possible economy of force. And, as the swinging leg is a true pendulum—the time of vibration of which depends, other things being alike, upon its length (short pendulums vibrating more quickly than long ones),—it follows that, on the average, the natural step of short-legged people is quicker than that of long-legged ones.

In *running*, there is a period when both legs are off the ground. The legs are advanced by muscular contraction, and the lever action of each foot is swift and violent. Indeed, the action of each leg resembles, in violent running, that which, when both legs act together, constitutes a *jump*, the sudden extension of the legs adding to the impetus, which, in slow walking, is given only by the feet.

21. Perhaps the most singular motor apparatus in the body is the *larynx*, by the agency of which *voice* is produced.

The essential conditions of the production of the human voice are:—

(*a*) The existence of the so-called *vocal chords*.

(*b*) The parallelism of the edges of these chords, without which they will not vibrate in such a manner as to give out sound.

(*c*) A certain degree of tightness of the vocal chords, without which they will not vibrate quickly enough to produce sound.

(*d*) The passage of a current of air between the parallel edges of the vocal chords of sufficient power to set the chords vibrating.

22. The larynx is a short tubular box opening above into the botton of the pharynx and below into the top of the trachea. Its framework is supplied by certain cartilages more or less movable on each other, and these are connected together by joints, membranes, and muscles. Across the middle of the larynx is a transverse partition, formed by two folds of the lining mucous membrane, stretching from either side, but not quite meeting in the middle line. They thus leave, in the middle line, a chink or slit, running from the front to the back, called the *glottis*. The two edges of this slit are not round and flabby, but sharp and, so to speak, clean cut; they are also strengthened by a quantity of elastic tissue, the fibres of which are disposed lengthways in them. These sharp free edges of the *glottis* are the so-called *vocal chords* or *vocal ligaments*.

23. The *thyroid* cartilage (Fig. 56, *Th*) is a broad plate of gristle bent upon itself into a V shape, and so disposed that the point of the V is turned forwards, and constitutes what is commonly called "Adam's apple." Above, the thyroid cartilage is attached by ligament and membrane to the *hyoid* bone (Fig. 56, *Hy*). Below and behind, its broad sides are produced into little elongations or horns, which are articulated by ligaments with the outside of a great ring of cartilage, the *cricoid* (Fig. 56, *Cr*), which forms, as it were, the top of the windpipe.

The *cricoid* ring is much higher behind than in front, and a gap, filled up by membrane only, is left between its upper edge and the lower edge of the front part of the thyroid, when the latter is horizontal. Consequently, the thyroid cartilage, turning upon the articulations of its horns with the hinder part of the cricoid, as upon hinges, can be moved up and down through the space occupied by

this membrane; or, if the thyroid cartilage is fixed, the cricoid cartilage moves in the same way upon its articulations with the thyroid. When the thyroid moves downwards or the cricoid upwards, the distance between the front part of the thyroid cartilage and the back of the cricoid is necessarily increased; and when the reverse movement takes place the distance is diminished. There is, on each side, a large muscle, the *crico-thyroid*, which passes from the outer side of the cricoid cartilage obliquely upwards

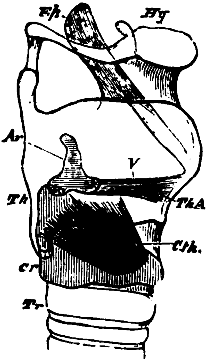


FIG. 56.

Diagram of the larynx, the thyroid cartilage (*Th*) being supposed to be transparent, and allowing the right arytenoid cartilage (*Ar*), vocal chords (*V*), and thyro-arytenoid muscle (*ThA*), the upper part of the cricoid cartilage (*Cr*), and the attachment of the epiglottis (*Ep*) to be seen. *C.th*, the right crico-thyroid muscle; *Tr*, the trachea; *Hy*, the hyoid bone.

and backwards to the thyroid, and pulls the latter down; or, if the thyroid is fixed, pulls the cricoid up (Fig. 56, *C.th*).

24. Perched side by side upon the upper edge of the back part of the cricoid cartilage are two small irregularly-shaped but, roughly speaking, pyramidal cartilages, the *arytenoid* cartilages (Fig. 58, *Ary*). Each of these is articulated by its base with the cricoid cartilage by means of a shallow joint which permits of very varied move-

ments, and especially allows the front portions of the two arytenoid cartilages to approach, or to recede from, each other.

It is to the forepart of one of these arytenoid cartilages that the hinder end of each of the two vocal ligaments is fastened; and they stretch from these points horizontally across the cavity of the larynx, to be attached, close together, in the re-entering angle of the thyroid cartilage rather lower than half-way between its top and bottom.

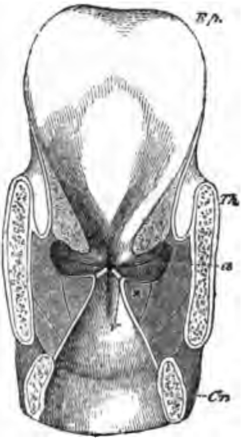


FIG. 57.—VERTICAL AND TRANSVERSE SECTION THROUGH THE LARYNX, THE HINDER HALF OF WHICH IS REMOVED.

Ep, Epiglottis; *Th*, thyroid cartilage; *a*, cavities called the *ventricles of larynx* above the vocal ligaments (*V*); × the right thyro-arytenoid muscle cut across; *Cr*, the cricoid cartilage.

Now when the arytenoid cartilages diverge, as they do when the larynx is in a state of rest, it is evident that the aperture of the glottis will be V-shaped, the point of the V being forwards, and the base behind.

For, in front, or in the angle of the thyroid, the two vocal ligaments are fastened permanently close together,

whereas, behind, their extremities will be separated as far as the arytenoids, to which they are attached, are separated from each other. Under these circumstances a current of air passing through the glottis produces no sound, the parallelism of the vocal chords being wanting; whence it is that, ordinarily, expiration and inspiration take place quietly. Passing from one arytenoid cartilage to the other, at their posterior surfaces are certain muscles called the *posterior arytenoid* (Fig. 58, *Ar.p.*). There are

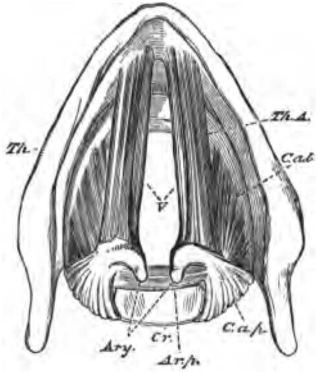


FIG. 58.—THE PARTS SURROUNDING THE GLOTTIS PARTIALLY DISSECTED AND VIEWED FROM ABOVE.

Th, the thyroid cartilage; *Cr*, the cricoid cartilage; *V*, the edges of the vocal ligaments bounding the glottis; *Ary*, the arytenoid cartilages; *Th.A*, thyro-arytenoid; *C.a.l*, lateral crico-arytenoid; *C.a.p*, posterior crico-arytenoid; *Ar.p*, posterior arytenoid muscles.

also two sets of muscles connecting each arytenoid with the cricoid, and called from their positions respectively the *posterior* and *lateral crico-arytenoid* (Fig. 58, *C.a.p.* *C.a.l.*). By the more or less separate or combined action of these muscles, the arytenoid cartilages, and especially the front part of these cartilages and, consequently, the hinder ends of the vocal chords attached to them, may be made to approach or recede from each other, and thus the vocal chords rendered parallel or the reverse.

We have seen that the crico-thyroid muscle pulls the thyroid cartilage down, or the cricoid cartilage up, and thus increases the distance between the front of the thyroid and the back of the cricoid, on which the arytenoids are seated. This movement, the arytenoids being fixed, must tend to pull out the vocal chords lengthways, or in other words to tighten them.

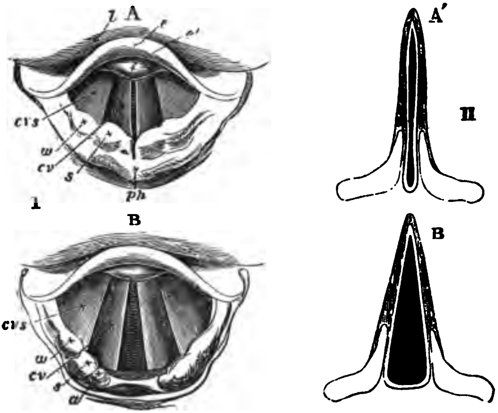


FIG. 59.

I. View of the human larynx from above as actually seen by the aid of the instrument called the laryngoscope; A, in the condition when voice is being produced; B, at rest when no voice is produced.

_e._ Epiglottis (foreshortened).

_c.v._ The vocal chords.

_c.v.s._ The so-called false vocal chords, folds of mucous membrane lying above the real vocal chords.

_a._ Elevation caused by the arytenoid cartilages.

_s.w._ Elevations caused by small cartilages connected with the arytenoids.

_l._ Root of the tongue.

II. Diagram of the same.

Running from the re-entering angle in the front part of the thyroid, backward, to the arytenoids, alongside the vocal chords (and indeed imbedded in the transverse folds, of which the chords are the free edges) are two strong muscles, one on each side (Fig. 58, *Th.A.*), called *thyro-*

arytenoid. The effect of the contraction of these muscles is to pull up the thyroid cartilage after it has been depressed by the crico-thyroid muscles, (or to pull down the cricoid after it has been raised,) and consequently to slacken the vocal chords.

Thus the parallelism (*b*) of the vocal chords is determined chiefly by the relative distance from each other of the arytenoid cartilages; the tension (*c*) of the vocal cords is determined chiefly by the upward or downward movement of the thyroid or cricoid cartilage; and both these conditions are dependent on the action of certain muscles.

The current of air (*d*) whose passage sets the chords vibrating is supplied by the movements of expiration, which, when the chords are sufficiently parallel and tense, produce that musical note which constitutes the voice, but otherwise give rise to no audible sound at all.

25. Other things being alike, the musical note will be low or high, according as the vocal chords are relaxed or tightened: and this again depends upon the relative predominance of the contraction of the crico-thyroid and thyro-arytenoid muscles. For when the thyro-arytenoid muscles are fully contracted, the thyroid cartilage will be raised, relatively to the cricoid, as far as it can go, and the vocal chords will be rendered relatively lax; while, when the crico-thyroid muscles are fully contracted, the thyroid cartilage will be depressed, relatively to the cricoid, as much as possible, and the vocal chords will be made more tense.

If, while a low note is being sounded, the tip of the finger be placed on the crico-thyroid space (which can be felt, through the skin, beneath the lower edge of the thyroid cartilage), and a high note be then suddenly produced, the crico-thyroid space will be found to be narrowed by the approximation of the front edges of the cricoid and thyroid cartilages. At the same time, however, the whole larynx is, to a slight extent, moved bodily upwards and thrown forwards, and the cricoid has a particularly distinct upward movement; this movement of the whole larynx must be carefully distinguished from the motion of the thyroid relatively to the cricoid.

The *range* of any voice depends upon the difference of tension which can be given to the vocal chords, in these

two positions of the thyroid cartilage. *Accuracy* of singing depends upon the precision with which the singer can voluntarily adjust the contractions of the thyro-arytenoid and crico-thyroid muscles—so as to give his vocal chords the exact tension at which their vibration will yield the notes required.

The *quality* of a voice—treble, bass, tenor, &c.—on the other hand, depends upon the make of the particular larynx, the primitive length of its vocal chords, their

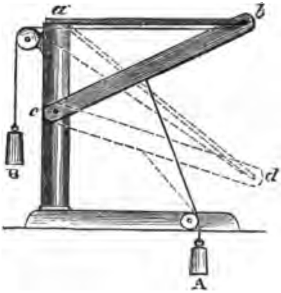


FIG. 60.

Diagram of a model illustrating the action of the levers and muscles of the larynx. The stand and vertical pillow represent the cricoid and arytenoid cartilages, while the rod (*b c*), moving on a pivot at *c*, takes the place of the thyroid cartilage; *a b* is an elastic band representing the vocal ligament. Parallel with this runs a cord fastened at one end to the rod *b c*, and, at the other, passing over a pulley to the weight B. This represents the thyro-arytenoid muscle. A cord attached to the middle of *b c*, and passing over a second pulley to the weight A, represents the crico-thyroid muscle. It is obvious that when the bar (*b c*) is pulled down to the position *c d*, the elastic band (*a b*) is put on the stretch.

elasticity, the amount of resonance of the surrounding parts, and so on.

Thus, men have deeper notes than boys and women, because their larynxes are larger and their vocal chords longer—whence, though equally elastic, they vibrate less swiftly.

26. *Speech* is voice modulated by the throat, tongue, and lips. Thus, voice may exist without speech; and it is

commonly said that speech may exist without voice, as in whispering. This is only true, however, if the title of voice be restricted to the sound produced by the vibration of the vocal chords; for, in whispering, there is a sort of voice produced by the vibration of the muscular walls of the lips which thus replace the vocal chords. A whisper is, in fact, a very low whistle.

The *modulation* of the voice into speech is effected by changing the form of the cavity of the mouth and nose, by the action of the muscles which move the walls of those parts.

Thus, if the pure *vowel* sounds—

E (as in *he*),	*A* (as in *hay*),	*A'* (as in *ah*),
O (as in *or*),	*O'* (as in *oh*),	*OO* (as in *cool*),

are pronounced successively, it will be found that they may be all formed out of the sound produced by a continuous expiration, the mouth being kept open, but the form of its aperture, and the extent to which the lips are thrust out or drawn in so as to lengthen or shorten the distance of the orifice from the larynx, being changed for each vowel. It will be narrowest, with the lips most drawn back, in *E*, widest in *A'*, and roundest, with the lips most protruded, in *OO*.

Certain *consonants* also may be pronounced without interrupting the current of expired air, by modification of the form of the throat and mouth.

Thus the aspirate, H, is the result of a little extra expiratory force—a sort of incipient cough. *S* and *Z*, *Sh* and *J* (as in *jugular*=*G* soft, as in *gentry*), *Th*, *L*, *R*, *F*, *V*, may likewise all be produced by continuous currents of air forced through the mouth, the shape of the cavity of which is peculiarly modified by the tongue and lips.

27. All the vocal sounds hitherto noted so far resemble one another, that their production does not involve the stoppage of the current of air which traverses either of the modulating passages.

But the sounds of *M* and *N* can only be formed by blocking the current of air which passes through the mouth, while free passage is left through the nose. For

M, the mouth is shut by the lips; for *N*, by the application of the tongue to the palate.

28. The other consonantal sounds of the English language are produced by shutting the passage through both nose and mouth; and, as it were, forcing the expiratory vocal current through the obstacle furnished by the latter, the character of which obstacle gives each consonant its peculiarity. Thus, in producing the consonants *B* and *P*, the mouth is shut by the lips, which are then forced open in this *explosive* manner. In *T* and *D*, the mouth passage is suddenly barred by the application of the point of the tongue to the teeth, or to the front part of the palate; while in *K* and *G* (hard, as in *go*) the middle and back of the tongue are similarly forced against the back part of the palate.

29. An artificial larynx may be constructed by properly adjusting elastic bands, which take the place of the vocal chords; and, when a current of air is forced through these, due regulation of the tension of the bands will give rise to all the notes of the human voice. As each vowel and consonantal sound is produced by the modification of the length and form of the cavities, which lie over the natural larynx, so, by placing over the artificial larynx chambers to which any requisite shape can be given, the various letters may be sounded. It is by attending to these facts and principles that various speaking machines have been constructed.

30. Although the tongue is credited with the responsibility of speech, as the "unruly member," and undoubtedly takes a very important share in its production, it is not absolutely indispensable. Hence, the apparently fabulous stories of people who have been enabled to speak, after their tongues had been cut out by the cruelty of a tyrant, or persecutor, may be quite true.

Some years ago I had the opportunity of examining a person, whom I will call Mr. R., whose tongue had been removed as completely as a skilful surgeon could perform the operation. When the mouth was widely opened, the truncated face of the stump of the tongue, apparently covered with new mucous membrane, was to be seen, occupying a position as far back as the level of the anterior pillars of the fauces. The dorsum of the tongue

was visible with diffculty; but I believe I could discern some of the circumvallate papillæ upon it. None of these were visible upon the amputated part of the tongue, which had been preserved in spirit; and which, so far as I could judge, was about 2½ inches long.

When his mouth was open, Mr. R. could advance his tongue no further than the position in which I saw it; but he informed me that, when his mouth was shut, the stump of the tongue could be brought much more forward.

Mr. R.'s conversation was perfectly intelligible; and such words as *think*, *the*, *cow*, *kill*, were well and clearly pronounced. But tin became *fin;* tack, *fack* or *pack;* toll, *pool;* dog, *thog;* dine, *vine;* dew, *thew;* cat, *catf;* mad, *madf;* goose, *gooth;* big, pig, *bich*, *pich*, with a guttural *ch.*

In fact, only the pronunciation of those letters the formation of which requires the use of the tongue was affected; and, of these, only the two which involve the employment of its tip were absolutely beyond Mr. R.'s power. He converted all *t's*, and *d's* into *f's*, *p's*, *v's*, or *th's*. *Th* was fairly given in all cases; *s* and *sh*, *l* and *r*, with more or less of a lisp. Initial *g's* and *k's* were good; but final *g's* were all more or less guttural. In the former case, the imperfect stoppage of the current of air by the root of the tongue was of no moment, as the sound ran on into that of the following vowel; while, when the letter was terminal, the defect at once became apparent.

LESSON VIII.

SENSATIONS AND SENSORY ORGANS.

1. THE agent by which all the motor organs (except the cilia) described in the preceding Lesson are set at work, is muscular fibre. But, in the living body, muscular fibre is, as a rule, made to contract by a change (Lesson V. § 31) which takes place in the *motor* or *efferent nerve*, which is distributed to it. This change again is generally effected by the activity of the *central nervous organ*, with which the motor nerve is connected. The central organ is thrown into activity, directly or indirectly, by the influence of changes which take place in nerves, called *sensory* or *afferent*, which are connected, on the one hand, with the central organ, and, on the other hand, with some other part of the body. Finally, the alteration of the afferent nerve is itself produced by changes in the condition of the part of the body with which it is connected; which changes usually result from external impressions.

2. Sometimes the central organ enters into a state of activity without our being able to trace that activity to any direct influence of changes in afferent nerves; the activity seems to take origin in the central organ, and the movements to which it gives rise are called 'spontaneous,' or 'voluntary.' Putting these cases on one side, it may be stated that a movement of the body, or of a part of it, is to be regarded as the effect of an influence

(technically termed a *stimulus* or *irritation*) applied directly, or indirectly, to the ends of *afferent nerves*, and giving rise to a modification of the condition of the particles or *molecules* which form the substance of the nerve fibres, *i.e.* to a *molecular change*, which is propagated from molecule to molecule along the fibres to the *central nervous organ* with which these are connected. The molecular activity of the afferent nerve sets up changes of a like order in the fibres and cells of the central organ; from these the disturbance is transmitted along the *motor nerves*, which pass from the central organ to certain muscles. And, when the disturbance in the molecular condition of the efferent nerves reaches the endings of those nerves in muscular fibres, a similar disturbance is communicated to the substance of the muscular fibres, whereby, in addition to the production of certain other phenomena to some of which reference has already been made (Lesson V. § 31), the particles of the muscular substance are made to take up a new position, so that each fibre shortens and becomes thicker.

3. Such a series of molecular changes as that just described is called a *reflex action:* the disturbance in the afferent nerves caused by the irritation being as it were *reflected* back, along the efferent nerves, to the muscles. But the name is not a good one, since it seems to imply that the molecular changes in the afferent nerve, the central organ, and the efferent nerve are all alike, and differ only in direction; whereas there is reason to think that they differ in many ways.

A reflex action may take place without our knowing anything about it, and hundreds of such actions are continually going on in our bodies without our being aware of them. But it very frequently happens that we learn that something is going on, when a stimulus affects our afferent nerves, by having what we call a *feeling* or *sensation*. We class sensations along with *emotions*, and *volitions*, and *thoughts*, under the common head of *states of consciousness*. But what consciousness is, we know not; and how it is that anything so remarkable as a state of consciousness comes about as the result of irritating nervous tissue, is just as unaccountable as any other ultimate fact of nature.

4. Sensations are of very various degrees of definiteness. Some arise within ourselves, we know not how or where, and remain vague and undefinable. Such are the sensations of *uncomfortableness*, of *faintness*, of *fatigue*, or of *restlessness*. We cannot assign any particular place to these sensations, which are very probably the result of affections of the afferent nerves in general brought about by the state of the blood, or that of the tissues in which they are distributed. And however real these sensations may be, and however largely they enter into the sum of our pleasures and pains, they tell us absolutely nothing of the external world. They are not only *diffuse*, but they are also *subjective* sensations.

5. What is termed the *muscular sense* is less vaguely localised than the preceding, though its place is still incapable of being very accurately defined. This muscular sensation is the feeling of resistance which arises when any kind of obstacle is opposed to the movement of the body, or of any part of it; and it is something quite different from the feeling of contact or even of pressure.

Lay one hand flat on its back upon a table, and rest a disc of cardboard a couple of inches in diameter upon the ends of the outstretched fingers; the only result will be a sensation of *contact*—the pressure of so light a body being inappreciable. But put a two-pound weight upon the cardboard, and the sensation of *contact* will pass into what appears to be a very different feeling, viz., that of *pressure*. Up to this moment the fingers and arm have rested upon the table; but now let the hand be raised from the table, and another new feeling will make its appearance—that of *resistance to effort*. This feeling comes into existence with the exertion of the muscles which raise the arm; and it is the consciousness of that exertion which goes by the name of 'the muscular sense.'

Any one who raises or carries a weight knows well enough that he has this sensation; but he may be greatly puzzled to say where he has it. Nevertheless, the sense itself is very delicate, and enables us to form tolerably accurate judgments of the relative intensity of resistances. Persons who deal in articles sold by weight are constantly enabled to form very precise estimates of the weight of such articles by balancing them in their hands; and in

this case, they depend in a great measure upon the muscular sense.

6. In the case of other sensations, each feeling arises out of changes taking place in a definite part of the body, is produced by a stimulus applied to that part of the body, and cannot be produced by stimuli applied to other parts of the body. Thus the sensations of *taste* and *smell* are confined to certain regions of the mucous membrane of the mouth and nasal cavities; those of *sight* and *hearing* to the particular parts of the body called the eye and the ear; and those of *touch*, though arising over a much wider area than the others, are nevertheless restricted to the skin and to some portions of the membranes lining the internal cavities of the body. Any portion of the body to which a sensation is thus restricted is called a *sense-organ.*

It may be here remarked that in the case of the sensation of touch, the simple feeling of contact is accompanied by information, not only as to what sense-organ, but also as to what part of that sense-organ, is being affected. When we touch a hot or a rough body with the tip of a finger, we are aware not only that we are dealing with a hot or a rough body, but also that the hot or rough body is in contact with the tip of the finger; we 'refer,' as is said, the sensation to that part of the tip of the finger which is being acted upon by the body in question. With the other sensations the case is different. When we smell a bad smell, though we know that we smell by the nose, we do not consider that the smell arises in the nose; we conclude that there is some object outside ourselves which is causing the bad smell. We refer the origin of the sensation to some external cause, and that even when the sensation is after all due to changes taking place in the nose itself independently of external objects, as in the unpleasant odours which accompany certain diseases of the nose. Similarly all our sensations of sight and of hearing are referred to external objects; and even in the case of taste, when a lump of sugar is taken into the mouth, we are simply aware of a sensation of sweetness and do not associate that sensation of sweetness with any particular part of the mouth, though, by the sense of touch, which the inside of the mouth also possesses, we can tell pretty

exactly whereabouts in the mouth the melting lump is lying.

7. In these sensations, thus arising in special sense-organs, and hence often spoken of as 'special' sensations, each sensation or feeling results from the application of a particular kind of stimulus to its appropriate sense-organ; and, in each case, the structure of the sense-organ is arranged in such a manner as to render that organ peculiarly sensitive to its appropriate stimulus.

Thus the sensations of sight are brought about by the action of the vibrations of the luminiferous ether; and the eye, or sense-organ of sight, is constructed in such a way that rays of light which falling on any other part of the body produce no appreciable effect, give rise to vivid sensations when they fall upon it.

Further we may, with more or less completeness, distinguish in each sense-organ two parts: an *essential* part, through which the agent producing the sensation (be it light, a series of sonorous vibrations, a sapid or odourous chemical substance, a change in temperature, or a variation in pressure), produces changes in certain structures which are peculiarly associated with the delicate terminations of the nerve distributed to the sense-organ; and an *accessory* part, not absolutely necessary to the sense but of great usefulness inasmuch as it assists in bringing the agent to bear, in the most efficient way, upon the *essential* part. In the case of the eye and ear this accessory part is extremely complicated, and indeed seems to form the greater part of the whole sense-organ; in the case of the other senses it is much more simple.

The essential part of each sense-organ is in turn composed of minute organs, which upon examination appear to be in reality modified epithelial cells; and the delicate terminations of the nerve filaments distributed to the sense-organ may, with more or less distinctness, be traced to these modified cells, in which indeed they seem to end. These minute organs, these modified epithelial cells, may be spoken of as *sense-organules;* they serve as intermediators in each case between the physical agent of the sensation and the sensory nerve. The physical agent is by itself unable to produce in the fibres of the sensory nerve those changes which, reaching the brain as nervous

impulses, give rise to the special sensations. Thus, as we shall presently see, rays of light falling upon the optic nerve cannot give rise to a sensation of sight. The physical agent must act first on the sense-organules, and these in turn act upon the filaments of the nerve. Thus light falling upon the sense-organules, situated in that essential part of the eye called the retina, sets up changes in them, these changes set up corresponding changes in the delicate nerve filaments which with the sense-organules go to make up the retina, and the changes in the nerve filaments propagated along the optic nerve to the brain give rise, in the latter, to sensations of sight.

Hence in the essential part of each sense-organ we have to distinguish between the sense-organules, *i.e.* the modified epithelium, and the terminal expansion of the sensory nerve; and further, in each sense-organ, there is added to this essential part a more or less complicated accessory part.

Lastly, in all these special sensations, there are certain phenomena which arise out of the structure of the sense-organ, and others which result from the operation of the central apparatus of the nervous system upon the materials supplied to it by the sense-organ.

8. The sense of TOUCH (including that of heat and cold) is possessed, more or less acutely, by all parts of the free surface of the body, and by the walls of the mouth and nasal passages.

Whatever part possesses this sense consists of a membrane (integumentary or mucous) composed of a deep layer made up of fibrous tissue containing a capillary network, and of a superficial layer consisting of epithelial or epidermic cells, among which are no vessels.

Wherever the sense of touch is delicate, the deep layer is not a mere flat expansion, but is raised up into multitudes of small, close-set, conical elevations (see Fig. 32), which are called *papillæ*. In the skin, the coat of epithelial or epidermic cells does not follow the contour of these papillæ, but dips down between them and forms a tolerably even coat over them. Thus, the points of the papillæ are much nearer the surface than the general plane of the deep layer whence these papillæ proceed. Loops of vessels enter the papillæ, and sensory nerve-fibres

are distributed to them. In some cases the nerve-fibre ends in a papilla in a definite organ, in what is called a *tactile corpuscle* (see Lesson XII.) or in a similar body called an *end-bulb*. Each of these organs consists essentially of an oval or rounded swelling formed by a modification and enlargement of the delicate fibrous sheath, or *neurilemma*, of the nerve; in the middle of the swelling the nerve fibre itself ends abruptly in a peculiar manner. These bodies are especially found in the papillæ of those localities which are endowed with a very delicate sense of touch, as in the tips of the fingers, the point of the tongue, &c.; and the papillæ which contain tactile corpuscles generally contain few or no blood-vessels.

The great majority, however, of the nerve-fibres going to the skin do not end in any such definite organs. They divide in the dermis into exceeding delicate minute filaments, the course and ultimate terminations of which are traced with the greatest difficulty. Some of the finest filaments, however, appear to pass into the epidermis and to be there lost among or possibly connected with some of the epidermic cells, especially those of the lower layers.

9. It is obvious, from what has been said, that no direct contact takes place between a body which is touched and the sensory nerve,—a thicker or thinner layer of epithelium, or epidermis, being situated between the two. In fact, if this layer is removed, as when a surface of the skin has been blistered, contact with the raw surface gives rise to a sense of pain, not to one of touch properly so called. Thus, in touch, the *essential* part of the sense-organ consists either of certain epithelial or epidermic cells of the general integument or of certain structures contained in the tactile corpuscles, end bulbs, and other similar organs which need not be considered here. These epithelial cells, very slightly modified apparently in the general skin, but more so in the tactile corpuscles and end bulbs, are the sense-organules; they serve as intermediators between the physical agent—pressure—and the terminal filaments of the sensory nerves. The *accessory* part of the sense-organ of touch is very slightly developed, being chiefly supplied by the variable number and form of the papillæ and the variable thickness and character of the layers of epidermic cells.

10. Certain very curious phenomena appertain to the sense of touch; some of these are probably in part due to these varying anatomical arrangements, to the varying thickness of the epidermis, and to the abundance or scantiness of special end-organs. Not only is tactile sensibility to a single impression much duller in some parts than in others—a circumstance which might in many cases be accounted for by the different thickness of the epidermic layer—but the power of distinguishing double simultaneous impressions is very different. Thus, if the ends of a pair of compasses (which should be blunted with pointed pieces of cork) are separated by only one-tenth or one-twelfth of an inch, they will be distinctly felt as two, if applied to the tips of the fingers; whereas, if applied to the back of the hand in the same way, only one impression will be felt; and, on the arm, they may be separated for a quarter of an inch, and still only one impression will be perceived.

Accurate experiments have been made in different parts of the body, and it has been found that two points can be distinguished by the tongue, if only one-twenty-fourth of an inch apart; by the tips of the fingers if one-twelfth of an inch distant; while they may be one inch distant on the cheek, and even three inches on the back, and still give rise to only one sensation.

11. The feeling of warmth, or cold, is the result of an excitation of sensory nerves distributed to the skin, which are possibly distinct from those which give rise to the sense of touch. And it would appear that the heat must be transmitted through the epidermic or epithelial layer, to give rise to this sensation; for, just as touching a naked nerve, or the trunk of a nerve, gives rise only to pain, so heating or cooling an exposed nerve, or the trunk of a nerve, gives rise not to a sensation of heat or cold, but simply to pain. Thus, if the elbow be dipped into a mixture of ice and salt, the cold first affects the skin of the elbow, giving rise to a sensation of cold at the elbow, but afterwards attacks the trunk of the ulnar nerve, which at the elbow lies not very far below the skin; and this latter effect is felt as a sensation, not of cold, but of pain. The pain, moreover, thus caused is not felt in the trunk of the nerve at the elbow, where the cold is acting,

but in the parts where the fibres of the nerve end, more particularly in the little and ring fingers.

Again, the sensation of heat, or cold, is relative rather than absolute. Suppose three basins be prepared, one filled with ice-cold water, one with water as hot as can be borne, and the third with a mixture of the two. If the hand be put into the hot-water basin, and then transferred to the mixture, the latter will feel cold; but if the hand be kept a while in the ice-cold water, and then transferred to the very same mixture, this will feel warm.

Like the sense of touch, the sense of warmth varies in delicacy in different parts of the body. The cheeks are very sensitive, more so than the lips; the palms of the hands are more sensitive to heat than their backs. Hence a washerwoman holds her flat-iron to her cheek to test the temperature, and one who is cold spreads the palms of his hands to the fire.

12. The organ of the sense of TASTE is the mucous membrane which covers the tongue, especially its back part, and the hinder part of the palate. Like that of the skin, the deep, or vascular, layer of the mucous membrane of the tongue is raised up into papillæ; but these are large, separate, and have separate coats of epithelium. Towards the tip of the tongue they are for the most part elongated and pointed, and are called *filiform;* over the rest of the surface of the tongue these are mixed with other larger papillæ, with broad ends and narrow bases, called *fungiform;* but towards its root there are a number of large papillæ, arranged in the figure of a V with its point backwards, each of which is like a fungiform papilla surrounded by a wall. These are the *circumvallate* papillæ (Fig. 61, *C.p.*). The larger of these papillæ have subordinate small ones upon their surfaces. They are very vascular, and they receive nervous filaments from two sources, the one the nerve called *glossopharyngeal*, the other the *gustatory*, which is a branch of the *fifth* nerve (see Lesson XI. § 18). The latter chiefly supplies the front of the tongue, the former its back and the adjacent part of the palate: and there is reason to believe that different taste sensations are supplied by the two nerves.

Certain of the epithelium cells covering the tongue and palate are modified in a peculiar way; these frequently occur in groups, being arranged somewhat like leaves in a bud, forming the so-called *taste buds*. These peculiar cells are the sense-organules of taste, and, with the delicate

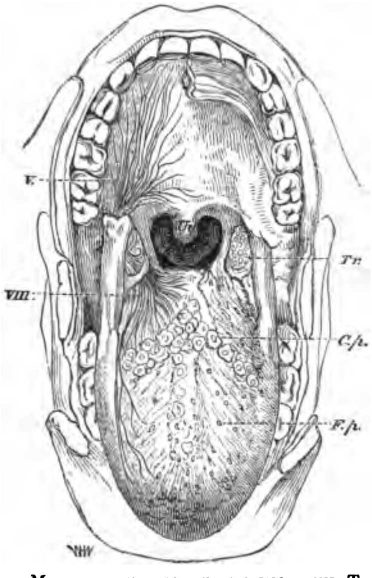


FIG. 61.—THE MOUTH WIDELY OPENED TO SHOW THE TONGUE AND PALATE.

Uv. the uvula; *Tn.* the tonsil between the anterior and posterior pillars of the fauces; *C.p.* circumvallate papillæ; *F.p.* fungiform papillæ. The minute filiform papillæ cover the interspaces between these. On the right side the tongue is partially dissected to show the course of the filaments of the glossopharyngeal nerve, *VIII.*

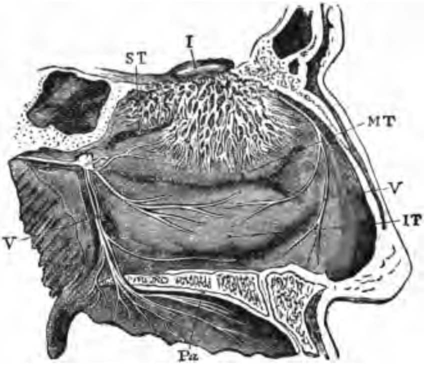
terminations of the glossopharyngeal and gustatory nerve which may be traced to them, constitute the *essential* parts of the organ of taste. The tongue itself, which by its movements brings the sapid substances into

immediate contact with these modified epithelium cells, may be regarded as the accessory part.

The great majority of the sensations we call taste, however, are in reality complex sensations, into which smell, and even touch, largely enter. When the sense of smell is interfered with, as when the nose is held tightly pinched, it is very difficult to distinguish the taste of various objects. An onion, for instance, the eyes being shut, may then easily be confounded with an apple.

13. The organ of the sense of SMELL is the delicate mucous membrane which lines the upper part of the nasal cavities. In this part the mucous membrane is distinguished from the rest of the mucous membrane of these cavities—firstly, by the character of its cells and by possessing no cilia; secondly, by receiving a large nervous supply from the olfactory, or first, pair of cerebral nerves, as well as a certain number of filaments of the fifth pair, whereas the rest of the mucous membrane is supplied from the fifth pair alone.

Each nostril leads into a spacious nasal chamber, separated, in the middle line, from its fellow of the other side, by a partition, or *septum*, formed partly by cartilage and partly by bone, and continuous with that partition which separates the two nostrils one from the other. Below, each nasal chamber is separated from the cavity of the mouth by a floor, the bony palate (Figs. 62 and 63); and when this bony palate comes to an end, the partition is continued down to the root of the tongue by a fleshy curtain, the soft palate, which has been already described. The soft palate and the root of the tongue together, constitute, under ordinary circumstances, a moveable partition between the mouth and the pharynx; and it will be observed that the opening of the larynx, the *glottis*, lies behind the partition; so that when the root of the tongue is applied close to the soft palate no passage of air can take place between the mouth and the pharynx. But in the upper part of the pharynx above the partition are the two hinder openings of the nasal cavities (which are called the *posterior nares*) separated by the termination of the septum; and through these wide openings the air passes, with great readiness, from the nostrils along the lower part of each nasal chamber to the glottis, or in the opposite direction. It is by means



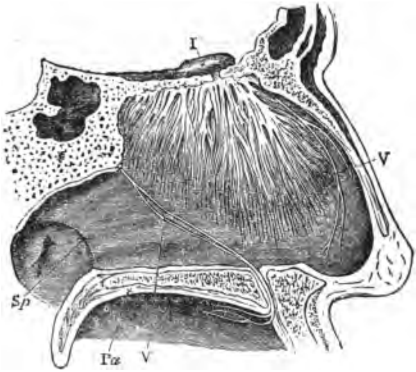


FIG. 62.—VERTICAL LONGITUDINAL SECTIONS OF THE NASAL CAVITY.

The upper figure represents the outer wall of the left nasal cavity; the lower figure the right side of the middle partition, or septum (*Sp.*) of the nose, which forms the inner wall of the right nasal cavity. *I.* the olfactory nerve and its branches; *V*, branches of the fifth nerve; *Pa.* the palate, which separates the nasal cavity from that of the mouth: *S.T.* the superior turbinal bone; *M.T.* the middle turbinal; *I.T.* the inferior turbinal. The letter *I* is placed in the cerebral cavity; and the partition on which the olfactory lobe rests, and through which the filaments of the olfactory nerves pass, is the cribriform plate.

of the passages thus freely open to the air that we breathe, as we ordinarily do, with the mouth shut.

Each nasal chamber rises, as a high vault, far above the level of the arch of the posterior nares—in fact, about as high as the depression of the root of the nose. The uppermost and front part of its roof, between the eyes, is formed by a delicate horizontal plate of bone, perforated like a sieve by a great many small holes, and thence called the

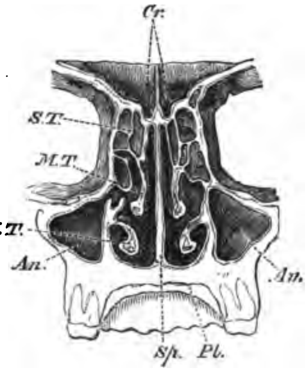


FIG. 63.—A TRANSVERSE AND VERTICAL SECTION OF THE OSSEOUS WALLS OF THE NASAL CAVITY TAKEN NEARLY THROUGH THE LETTER *I* IN THE FOREGOING FIGURE.

Cr. the cribriform plate; *S.T.*, *M.T.* the chambered superior and middle turbinal bones on which and on the septum (*Sp.*) the filaments of the olfactory nerve are distributed; *I.T.* the inferior turbinal bone; *Pl.* the palate; *An.* the *antrum* or chamber which occupies the greater part of the maxillary bone and opens into the nasal cavity.

cribriform plate (Fig. 63, *Cr.*). It is this plate (with the membranous structures which line its two faces) alone which, in this region, separates the cavity of the nose from that which contains the brain. The olfactory lobes, which are directly connected with, and form indeed a part of, the brain, enlarge at their ends, and their broad extremities rest upon the upper side of the cribriform plate, sending through it immense numbers of delicate filaments, the

olfactory nerves, which are distributed as follows (Fig. 62) :—

On each wall of the septum the mucous membrane forms a flat expansion, but on the side walls of each nasal cavity it follows the elevations and depressions of the inner surfaces of what are called the upper and middle turbinal, or spongy bones. These bones are called spongy because the interior of each is occupied by air cavities separated from each other by very delicate partitions only, and communicating with the nasal cavities. Hence the bones, though massive-looking, are really exceedingly light and delicate, and fully deserve the appellation of spongy (Fig. 63).

Over these upper and middle turbinal bones, and on both sides of the septum opposite to them, the mucous membrane is specially modified, and receives the name of olfactory mucous membrane; and it is to this olfactory mucous membrane that the filaments of the olfactory nerve passing through the cribriform plate are distributed.

There is a third light scroll-like bone distinct from these two, and attached to the maxillary bone, which is called the *inferior* turbinal, as it lies lower than the other two, and imperfectly separates the air passages from the proper olfactory chamber (Fig. 62). It is covered by the ordinary ciliated mucous membrane of the nasal passage, and receives no filaments from the olfactory nerve (Fig. 62).

In the non-olfactory part of the nasal mucous membrane the epithelium cells are ordinary ciliated epithelium cells (see Lesson XII.); but in the olfactory part the cells not only lose their cilia, but become peculiarly modified. Many of them become very slender and rod-shaped, and the delicate terminations of the olfactory nerve filaments appear to end in these modified epithelial cells, which indeed are the sense-organules of the organ of smell. The olfactory mucous membrane, with the filaments of the olfactory nerve ending in it, thus constitutes the essential part of the organ.

14. The accessory part of the organ may be described as follows :—

From the arrangements which have been described, it is clear that, under ordinary circumstances, the gentle inspiratory and expiratory currents will flow along the

comparatively wide, direct passages afforded by so much of the nasal chamber as lies below the middle turbinal; and that they will hardly move the air enclosed in the narrow interspace between the septum and the upper and middle spongy bones, which is the proper olfactory chamber.

If the air currents are laden with particles of odorous matter, these can only reach the olfactory membrane by diffusing themselves into this narrow interspace; and, if there be but few of these particles, they will run the risk of not reaching the olfactory mucous membrane at all, unless the air in contact with it be exchanged for some of the odoriferous air. Hence it is that, when we wish to perceive a faint odour more distinctly, we sniff, or snuff up the air. Each sniff is a sudden inspiration, the effect of which must reach the air in the olfactory chamber at the same time as, or even before, it affects that at the nostrils; and thus must tend to draw a little air out of that chamber from behind. At the same time, or immediately afterwards, the air sucked in at the nostrils entering with a sudden vertical rush, part of it must tend to flow directly into the olfactory chamber, and replace that thus drawn out.

The loss of smell which takes place in the course of a severe cold may, in part, be due to the swollen state of the mucous membrane which covers the inferior turbinal bones, impeding the passage of odoriferous air to the olfactory chamber.

15. The EAR, or organ of the sense of Hearing, is very much more complex than either of the sensory organs yet described; and in it both the essential and the accessory parts are much more highly developed.

The essential part, on each side of the head, consists, substantially, of a very peculiarly-formed membranous bag. This bag, when the ear first begins to be formed, is a simple round sac, but it subsequently takes on a very complicated form, and becomes divided into several parts, which receive special names. It is lodged in a cavity of correspondingly intricate shape, hollowed out of a solid mass of bone (called from its hardness *petrosal*), which forms part of the temporal bone, and lies at the base of the skull. The sac, however, does not completely fill

the cavity, so that a space is left between the bony walls and the contained sac. This space, which is continuous all round the sac, being interrupted at certain places only where the membranous sac is attached to the bony walls, contains a fluid provided by the lymphatics of the neighbourhood, and called *perilymph*.

The membranous sac, the walls of which consist chiefly of connective tissue, is lined by an epithelium, and contains a fluid of its own called *endolymph*. The perilymph, it will be understood, is quite distinct from the endolymph, the two fluids being separated by the walls of the membranous sac.

Over a great part of the interior of the membranous sac the epithelium is simple in character, but at certain places to be presently described it assumes special features, being greatly thickened, and bearing hair-like processes, or being otherwise modified, so as to be easily affected by even such slight movements as the vibrations which produce sound. Where these patches or tracts of modified or *auditory epithelium*, as it is called, exist, the membranous sac is more closely attached to the bony walls; and branches of the eighth, acoustic or auditory, nerve passing through channels in the bony walls, through the tissue attaching the membranous sac to the bony walls, and through the wall of the membranous sac itself, come into peculiar relation with, and end in, or among, the cells of these patches of auditory epithelium. It is only to the places where the epithelium is thus modified that filaments of the auditory nerve are distributed.

What takes place in hearing may briefly be stated as follows. The vibrations set up by a sounding body are conducted, by the accessory apparatus to be presently described, to the perilymph, and from thence through the walls of the membranous sac to the endolymph. As the vibrations travelling along the endolymph reach those particular places where the epithelium is modified, and where the filaments of the auditory nerve end, they in some way or other affect the epithelium cells. Through the intermediation of these cells the delicate endings of the auditory nerve are stimulated, so that molecular changes are set up in the substance

of the nerve, and transmitted along the nerve from particle to particle, until they reach that part of the brain the molecular disturbance of which gives rise to sensations of sound.

Thus, until the auditory epithelium is reached, that which takes place in the ear when we hear a sound is simply a transmission of vibrations of the same order as those which are produced by the sounding body; but the processes which intervene between the epithelium and the brain are not of the same kind; here there is no transmission of such vibrations, but what takes place is a series of changes of nerve substance of the same order as, though

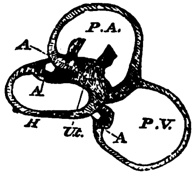


FIG. 64.—THE MEMBRANOUS LABYRINTH, TWICE THE NATURAL SIZE.

Ut. the *Utriculus*, or part of the vestibular sac, into which the semicircular canals open; *A*, *A*, *A*, the ampullæ; *P.A.* anterior vertical semicircular canal; *P.V.* posterior vertical semicircular canal; *H.* horizontal semicircular canal. The sacculus is not seen, as in the position in which the labyrinth is drawn the sacculus lies behind the utriculus. The white circles on the ampullæ of the posterior, vertical, and horizontal canals indicate the cut ends of the branches of the auditory nerve ending in those ampullæ; the branches to the ampulla of the anterior vertical canal are seen in the spaces embraced by the canal, as is also the branch to the utriculus.

perhaps not exactly like, those which are set up by the action of a stimulus on any other nerve (see Lesson V. § 31, VII. § 4).

16. The membranous bag, as I have said, is not simple but complicated; it consists of several parts. In the first place there is a somewhat oval sac, called the *utriculus* (Fig. 64, *Ut.*) into which open three hoop-like, semicircular canals. Of these two are placed vertically, one directed anteriorly, the other posteriorly, and are hence called the *anterior* (*P.A.*) and *posterior* (*P.V.*) *vertical semicircular canals.* The third is placed horizontally and directed

outwards, hence it is called the *exterior horizontal semicircular canal* (Fig. 64, *H*). It will be observed that the three canals thus lie in the three directions of space; this has nothing to do with judging the directions of sound, but may possibly have a relation to other functions of the canals. Each of these three hoops is dilated at one of its two ends, where it opens into the utriculus, into what is called an *ampulla* (Fig. 64, *A*, *A*, *A*), the other end

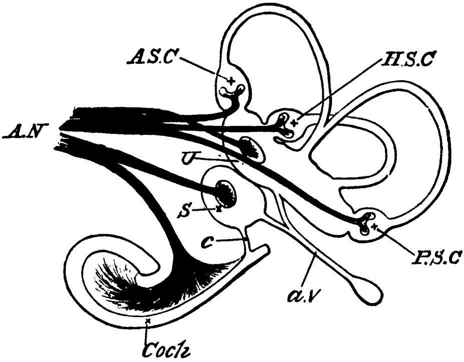


FIG. 65.

Diagram to illustrate the endings of the auditory nerve in the membranous labyrinth and cochlea. N.B. *The drawing is diagrammatic.*
A.N. auditory nerve dividing into several branches, and ending:—at *A.S.C.* in the ampulla of the anterior vertical semicircular canal: *P.S.C.* do. posterior vertical: *E.S.C.* do. external horizontal: *U.* in the utriculus: *S.* in the sacculus. *Coch*, the ending all along the canalis cochlearis. *A.V.* canal uniting the interior of utriculus with that of sacculus. *C.* canal joining the sacculus to the canalis cochlearis.

having no ampulla. Thus there is one ampulla to each canal. Those ends of the two vertical canals which are not dilated into ampullæ join together (Fig. 65), before they open into the utriculus.

On each ampulla is a ridge or crest, called *crista acustica*, placed crosswise, and projecting into the cavity of the canal. Each crest is formed partly by an infolding and thickening of the connective tissue wall of the ampulla,

and partly by a thickening of the epithelium, which here has the peculiar characters already referred to. A similar but oval patch of thickened, modified, auditory epithelium, with a thickening of the wall beneath it, is found in the utriculus itself; this is called a *macula acustica.*

Attached to the utriculus is a similar smaller sac (forming another division of the primitive membranous bag) called the *sacculus hemisphericus*, on the walls of which is a similar rounded patch of modified epithelium, or *macula.* The cavity of the sacculus is cut off from that of the utriculus, except for a curious roundabout connection by means of a narrow canal (Fig. 65, *av.*).

The utriculus and sacculus are often called the *vestibule;* and with the three semicircular canals receive the name of the *membranous labyrinth.* It will be remembered that this membranous labyrinth, filled with endolymph, lies in an intricate cavity with bony walls called the *osseous labyrinth*, and that between the walls of the bony and the membranous labyrinth, which corresponds largely but not wholly in form, is a space filled with perilymph.

Branches of the auditory nerve pass to this membranous labyrinth and send fibres (Fig. 65) to the three crests of the three ampullæ, to the patch on the utriculus, and to the patch on the sacculus. In each crest and each patch the epithelium is thickened and modified, and although the crests are slightly different in structure from the patches, the general features are the same in all. Whereas over the rest of the inside of the membranous labyrinth the epithelium consists (Fig. 66, *e*) of a single layer of low, rather flat cells, in the crests and patches the cells lie several deep, and are of a peculiar form. Some are conical or cylindrical, and some are spindle-shaped, and either the one or the other, or, according to some authors, both, bear stiff hair-like filaments (Fig. 66, *a.h. A.B. a.h.*) projecting into the cavity of the labyrinth. These filaments, often called auditory hairs, appear at first sight to resemble cilia, but they are stiff, and unlike cilia have no active movement of their own. They are longer and more conspicuous in the crests of the ampullæ than in the patches of the utriculus and sacculus. The fibres of the auditory nerve may be traced through the connective tissue wall of the crest or patch into the epithelium,

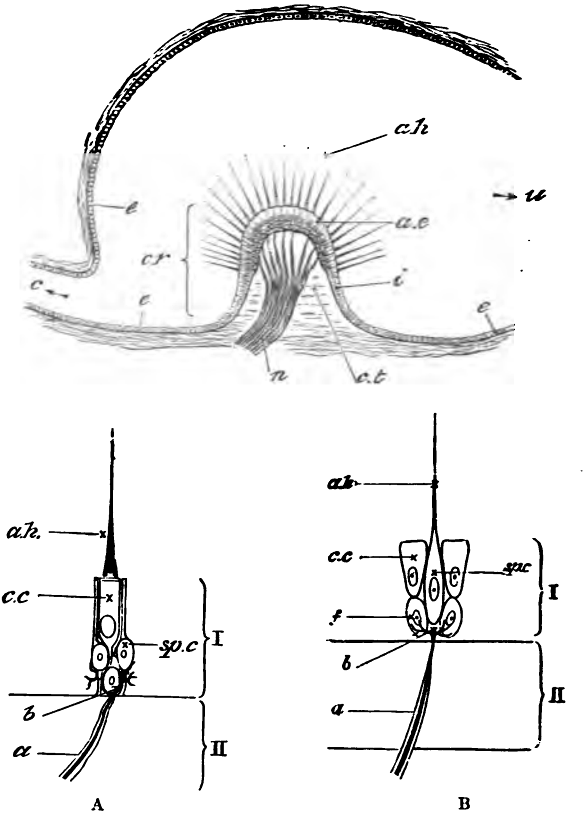


FIG. 66.—LONGITUDINAL SECTION OF AMPULLA, CUTTING THE CREST CROSSWISE (SOMEWHAT DIAGRAMMATIC).

c, one end of the ampulla forming the semicircular canal, *u*, the other end opening into the utricle; *e*, ordinary epithelium lining the greater part of the ampulla; *cr.* The crest with *a.e.* auditory epithelium; *a.h.* auditory hairs; *c.t.* connective tissue support to the auditory epithelium; *n*, fibres of the auditory nerve passing into the auditory epithe-

where they break up into a delicate network among the cells (Fig. 66, *A.B. b.*); but it is not as yet exactly determined how the filaments of this network end, whether they actually join the conical cells, or the spindle cells, or merely lie in contact with them.

However this may be, it is very clear that the vibrations, or waves of sound, reaching the ear from some sounding body, in passing along the endolymph, set in movement these hairs, very much as waves of the wind set in movement stalks of standing corn, and that the movements of the hairs, by help of the cells to which the hairs belong, excite the delicate filaments of the nervous network below, and so set up disturbances or impulses which pass along the auditory nerve to the brain.

In the utriculus and sacculus where, as has been said, the hairs are not so conspicuous, the endolymph contains a number of small calcareous particles called *otoliths*, and these are supposed by many to be of use in increasing the effect of the waves in the endolymph. In bathing in a tolerably smooth sea, on a rocky shore, the movement of the little waves as they run backwards and forwards is hardly felt by any one lying down; but in bathing on a sandy and gravelly beach the pelting of the showers of little stones and sand, which are raised and let fall by each wavelet, makes a very definite impression on the nerves of the skin. And it may be that the movements of these otoliths in a similar way produce a greater effect on the epithelium than would the mere waves of the endolymph; but in some of the lower animals these minute particles are replaced by one large stone which seems rather to act

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lium; *i*, epithelium intermediate between the auditory epithelium and the ordinary epithelium of the rest of the ampulla.

A and B. Diagrams to illustrate the character of the cells of the auditory epithelium, and the two views taken as to the relation of the auditory hairs to the cells. In both A and B, I is the auditory epithelium, II the connective tissue on which it rests, and *a*, a fibre of the auditory nerve passing through II, and dividing into fine branching filaments in I, at *b*.

In A, *c.c.* cylindrical cells bearing auditory hairs, *a.h.*; each cell bears a group of fine hairs which adhere together as a long narrow cone; *sp.c.* spindle-shaped cells, not bearing hairs.

In B, *c.c.* cylindrical cells not bearing hairs, *sp.c.* spindle-shaped cells bearing the auditory hair, *d*, and supposed to be connected with the nerve-filaments; *f* other supporting cells.

In both A and B, the fibre, *a*, of the auditory nerve passes into the epithelium, and ends in fine branches, *b*.

as a damper; so that the exact use of the otoliths must be left at present undecided.

17. An important part of the essential apparatus yet remains to be described, and that is the *cochlea*.

Connected with the sacculus by a narrow canal is an extension of the original membranous sac, in the form of a long tube closed at the end (Fig. 65, *Coch.*). This cochlear tube, like the parts of the membranous sac already described, is lined with epithelium, contains endolymph, and is lodged in a bony cavity filled with perilymph. So far it resembles the labyrinth, but in many other respects it is very different.

In the first place, in the labyrinth, the membranous sac very closely follows the contour of the bony walls, so that in a section of a semicircular canal, for instance, the membranous canal presents a circular contour lying in the larger circular contour of the bony canal. But in the cochlea, on the contrary, the contour of the cochlear tube is, along its whole length, totally different from that of the containing cavity; for, in transverse section, while the contour of the containing cavity is almost circular, that of the cochlear tube itself is nearly triangular. The cochlear tube in fact is, in shape, what is often called triangular (as when we speak of a triangular file), but should be called *trihedral;* that is to say it has three sides or faces (and three edges); one of the sides is however not flat but convex, *i.e.* bulges somewhat outwards.

In the second place, in the labyrinth, the sac is for the most part free from the bony walls, being attached only at the places where the nerve fibres pass into it, and, more loosely, at some few other points; but in the cochlea, on the contrary, the cochlear tube closely adheres to the bony wall, along the whole length of the tube, in two regions, namely, over the whole of that face of the trihedral tube which has just been described as being convex, and at the edge opposite. Take a round ruler, make a paper case which just fits it, and close the case at one end. Then pare down the ruler on two sides until it has two flat faces meeting at an edge, and slide it into the case, so that it does not quite reach the closed end. The ruler, if it were hollow, would represent the cochlear tube; and it will be observed that it divides the cavity of the case

into two passages, which are quite distinct from each other, except at the end of the case to which the ruler does not reach. In a similar way, the cochlear tube, containing endolymph, divides the cavity containing perilymph, in which it lies, into two passages, called *scalæ*, which are seen in section (Fig. 67) to be placed one above and the other below the triangular cavity of the cochlear tube itself, and which communicate with each other at the far end of the cochlear tube, but not elsewhere.

In one point, however, the comparison with the ruler and its case is not exact. The cochlear tube is not nearly so wide as the containing cavity; and the sharp edge

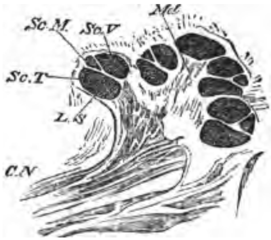

FIG. 67.—A SECTION THROUGH THE AXIS OF THE COCHLEA, MAGNIFIED THREE DIAMETERS.

Sc.M. scala media; *Sc.V.* scala vestibuli; *Sc.T.* scala tympani; *L.S.* lamina spiralis; *Md.* bony axis, or modiolus, round which the scalæ are wound; *C.N.* cochlear nerve.

opposite the convex adherent face would not be in direct connexion with the bony walls, were it not for a bony ledge which, projecting from the bony walls towards the thin edge of the cochlear tube, is united to it by membrane and thus forms a partition or *septum*, which separates the two scalæ in the region where the cochlear tube itself would otherwise leave a communication between them.

In the third place, the cochlear tube is not straight or even simply curved, but is twisted up on itself, into a spiral of two and a half turns. In these twists it is accompanied by the cavities above and below it, and also by the septum spoken of above, which thus takes a spiral course,

and is spoken of as the *lamina spiralis* (Figs. 67, 68, *l.s.*). The whole arrangement somewhat resembles the shell of a snail; hence the name. All along the spiral the edge of the cochlear tube attached to the lamina spiralis is directed inwards and the convex face outwards; so that when a section is made through the axis of the spiral a succession of rounded spaces are cut through, each space exhibiting, above and below, the somewhat half-moon-shaped section of a *scala*, the two scalæ being separated on the outer side, by the cochlear tube, and, on the inner, by the lamina spiralis (Fig. 67).

The triangular cavity which, as we have seen, contains endolymph, and is continuous with the sacculus, is called the *canalis cochlearis*, or *scala media* (because it lies between the two other cavities). The upper of the two cavities containing perilymph, when traced down to the bottom of the spiral, is found to be continuous with the cavity containing perilymph which surrounds the vestibule (*i.e.* the utriculus and sacculus); hence it is called the *scala vestibuli*. The lower cavity, when similarly traced to the bottom of the spiral, ends against the inner wall of a part of the ear to be presently described, called the *tympanum*, by an opening, called the *fenestra rotunda*, which is closed by a membrane. Hence this lower cavity is called the *scala tympani*. Thus the scala vestibuli and scala tympani begin at different points, and are separated along their whole course by the cochlear tube and the lamina spiralis except at the very tip of the spiral, where these latter end; here the two scalæ are prolonged beyond the cochlear tube and join together, forming a common space, as seen at the top of Fig. 67.

The vibrations of sound are brought, as we shall see, to the perilymph chamber of the vestibule, whence they spread on the one hand over the semicircular canals, and on the other into the scala vestibuli. Passing upwards, in the spiral along the scala vestibuli, they enter at the summit the scala tympani, along which they descend, and are eventually lost at the fenestra rotunda in which that scala ends.

18. But besides this peculiar arrangement of the perilymph chamber, there are other and still more important differences between the cochlea and the labyrinth.

The auditory nerve is, as we have seen, distributed to

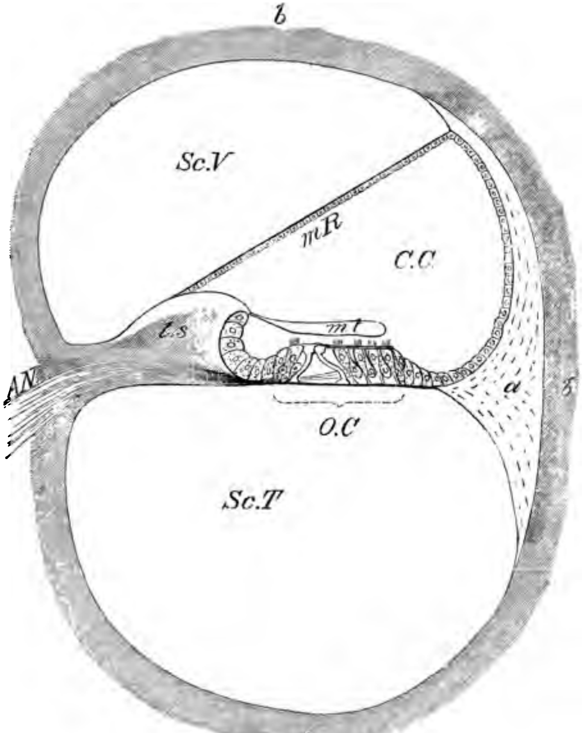

FIG. 68.—SECTION OF COIL OF COCHLEA.

Sc.V. scala vestibuli; *Sc.T.* scala tympani; *C.C.* canalis cochlearis, or scala media; *O.C.* organ of Corti; *M.R.* membrane of Reissner, *m.t.* membrana tectoria (a gelatinous membrane overlying the organ of Corti, and supposed to act as a damper). *A.N.* fibres of the auditory nerve running in *l.s.*, the lamina spiralis, and ending in the organ of Corti; *a*, connective tissue cushion to which the basilar membrane is attached on the outside; *b*, bony walls.

The figure has, for simplicity's sake, been made somewhat diagrammatic. The lamina spiralis has been drawn too short; the proportions of the lamina spiralis and the scalæ are more exactly rendered in Fig. 67.

certain parts only of the membranous labyrinth, namely, to the crests of the ampullæ and to the patches on the utriculus and the sacculus; but, in the case of the cochlea, fibres, running in canals excavated in the bony core of the spiral, and in the lamina spiralis (Fig. 68, *A.N.*) run to and end in the canalis cochlearis along its whole length, from the bottom to the top of the spiral, Fig. 65, *Coch.* And the mode of ending of these nerves is very peculiar.

If we examine a section of one of the spirals of the cochlea (Fig. 68), we see that the upper side of the cochlear tube (that which separates it from the scala vestibuli) is formed by a thin membrane (called the membrane of Reissner Fig. 68 *M.R.*) lined internally by simple epithelium. The outer convex side of the cochlear tube, that side by which it is firmly attached to the bony wall, is also lined internally by simple epithelium. Neither here nor in the membrane of Reissner do any fibres of the auditory nerve end. But the remaining side of the tube, that which looks towards the scala tympani, possesses on its inner face, along the whole length of the tube, from the bottom to the top of the spiral a very remarkable and strangely modified epithelium; and, along the whole length of the tube, fibres of the auditory nerve pass into and end among the cells of this epithelium, which is spoken of as the *organ of Corti.* (Fig. 68, *O.C.*)

The membrane which separates the cavity of the cochlear tube from the scala tympani, and on which the organ of Corti is placed, is of a peculiar character, specially adapted for being thrown into vibrations, and is called the *basilar membrane.* The organ of Corti itself consists of, in the first place, the so-called *rods of Corti*, peculiarly shaped long bodies, which are seen in section leaning, as it were, against each other. There is an inner row of these and an outer row all along the spiral, each row consisting of several (four to six) thousands of rods. On the inside and on the outside of the rods are very peculiar epithelial cells, also arranged into rows, each row consisting of several thousand cells. Each of these cells bears short hairs on its free surface, hence they are called hair-cells, inner and outer; and the auditory nerves passing through the lamina spiralis, reach the cochlear tube along the whole length of the spiral, and end in filaments

which are lost in the organ of Corti, but are probably connected with the hair-cells.

19. These essential parts of the organ of hearing, the membranous labyrinth and the canalis cochlearis, are, we have seen, lodged in chambers of the petrous part of the temporal bone.

In the fresh state, this collection of chambers in the

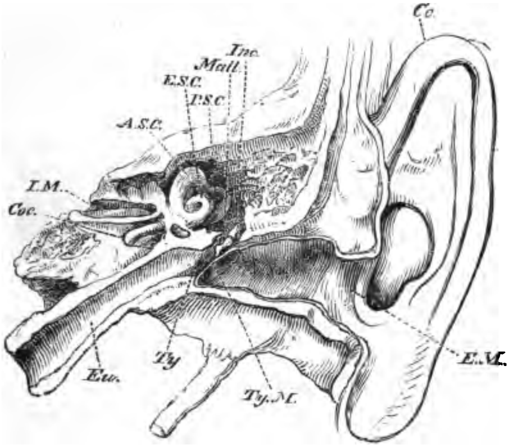

FIG. 69.—TRANSVERSE SECTION THROUGH THE SIDE WALLS OF THE SKULL TO SHOW THE PARTS OF EAR.

Co. Concha or external ear; *E.M.* external auditory meatus; *Ty.M.* tympanic membrane; *Inc. Mall.* incus and malleus; *A.S.C.*, *P.S.C.*, *E.S.C.* anterior, posterior, and external semicircular canals; *Coc.* cochlea; *Eu.* Eustachian tube; *I.M.* internal auditory meatus, through which the auditory nerve passes to the organ of hearing.

petrous bone is perfectly closed; but, in the dry skull, there are two wide openings, termed *fenestræ*, or windows, on its outer wall; *i.e.*, on the side nearest the outside of the skull. Of these fenestræ, one, termed *ovalis* (the oval window), is situated in the wall of the vestibular cavity; the other, *rotunda* (the round window), behind and below this, is, as we have seen, the open end of the *scala tympani*

at the base of the spiral of the cochlea. In the fresh state, each of these windows or fenestræ is closed by a fibrous membrane, continuous with the periosteum of the bone.

The *fenestra rotunda* is closed by membrane only; but fastened to the centre of the membrane of the *fenestra ovalis*, so as to leave only a narrow margin, is an oval plate of bone, part of one of the little bones to be described shortly.

20. The outer wall of the internal ear is still far away from the exterior of the skull. Between it and the visible

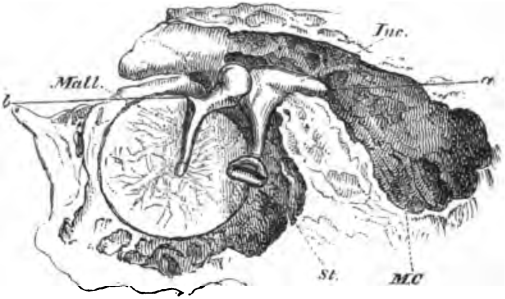

FIG. 70.—THE MEMBRANE OF THE DRUM OF THE EAR, WITH THE SMALL BONES OF THE EAR SEEN FROM THE INNER SIDE; AND THE WALLS OF THE TYMPANUM, WITH THE AIR-CELLS IN THE MASTOID PART OF THE TEMPORAL BONE.

The petrous part of the temporal bone containing the labyrinth is supposed to be removed, the foot-plate of the stapes having been detached from the fenestra ovalis.

M.C. mastoid cells; *Mall.* malleus; *Inc.* incus; *St.* stapes; *a b*, lines drawn through the horizontal axis on which the malleus and incus turn.

opening of the ear, in fact, are placed in a straight line, first, the drum of the ear, or *tympanum*; secondly, the long external passage, or *meatus* (Fig. 69).

The drum of the ear and the external meatus, which together constitute the middle ear, would form one cavity, were it not that a delicate membrane, the tympanic membrane (*Ty.M.* Fig. 69), is tightly stretched in an oblique direction across the passage, so as to divide the comparatively small cavity of the drum from the meatus.

The membrane of the tympanum thus prevents any communication, by means of the meatus, between the drum and the external air, but such a communication is provided, though in a roundabout way, by the Eustachian tube (*Eu.* Fig. 69), which leads directly from the fore part of the drum inwards to the roof of the pharynx, where it opens.

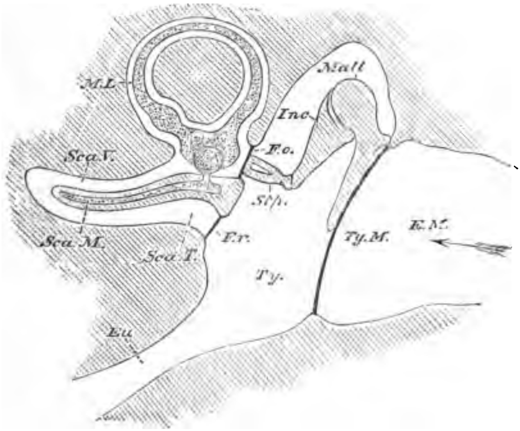

FIG. 71.—A DIAGRAM ILLUSTRATIVE OF THE RELATIVE POSITIONS OF THE VARIOUS PARTS OF THE EAR.

E.M. external auditory meatus; *Ty.M.* tympanic membrane; *Ty.* tympanum; *Mall.* malleus; *Inc.* incus; *Stp.* stapes; *F.o.* fenestra ovalis; *F.r.* fenestra rotunda; *Eu.* Eustachian tube; *M.L.* membraneous labyrinth, only one semicircular canal with its ampulla being represented; *Sca.V.*, *Sca.T.*, *Sca.M.*, the scalæ of the cochlea, which is supposed to be unrolled.

21. Three small bones, the auditory ossicles, lie in the cavity of the tympanum. One of these is the *stapes*, a small bone shaped like a stirrup. It is the foot-plate of this bone which, as already mentioned, is firmly fastened to the membrane of the *fenestra ovalis*, while its hoop projects outwards into the tympanic cavity (Fig. 70).

Another of these bones is the *malleus* (*Mall.* Figs. 69, 70, 71), or hammer-bone, a long process, the so-called *handle*,

of which is fastened to the inner side of the tympanic membrane (Fig. 70); while a very much smaller process, the *slender process*, is fastened, as is also the body of the malleus, to the bony wall of the tympanum by ligaments. The rounded surface of the head of the malleus fits into a corresponding hollowed surface in the end of a third bone, the *incus* or anvil bone, thus forming a joint of a somewhat peculiar character. The incus has two processes; of these one, the shorter, is horizontal, and rests upon a support afforded to it by the walls of the tympanum; while the other, the longer, is vertical, descends almost parallel with the long process of the malleus, and articulates[1] with the stapes (Figs. 70 and 71).

The three bones thus form a movable chain between the fenestra ovalis and the tympanic membrane. The malleus and incus are, by the peculiar joint spoken of above, articulated together in such a manner that they may practically be considered as forming one bone which turns upon a horizontal axis. This axis passes through the horizontal process of the incus and the slender process of the malleus, and its ends rest in the walls of the tympanum. Its general direction is represented by the line *a b* in Fig. 70, or by a line perpendicular to the plane of the paper, passing through the head of the malleus in Fig. 71.

The two bones may be roughly compared to two spokes of a wheel, of which the axle is represented by the axis just described; it should be added, however, that one spoke, the incus, is shorter than the other, and that the movement of the two spokes is limited to a very small arc of a circle.

When the membrane of the drum, thrown into vibration by some sound, moves inwards and outwards in its vibrations, it necessarily carries with it, in each inward and outward movement, the handle of the malleus which is attached to it. But with each inward and outward movement of the handle of the malleus, the long process of the incus also moves inward and outward, carrying with it the stapes which is attached to its end. Hence each vibration,

[1] A minute bone, the *os orbiculare*, intervenes between the end of the process of the incus and the stapes, so that the stapes is in reality articulated with the os orbiculare, which in turn is fastened to the process of the incus. For simplicity's sake, mention of this is omitted above.

each inward thrust, and each outward or backward return of the membrane of the drum, produces by means of the chain of ossicles a corresponding vibration of the membrane of the fenestra ovalis to which the stapes is attached; [1] but the vibrations of this membrane are in turn communicated to the perilymph of the labyrinth and cochlea. Thus by means of the chain of ossicles, and the membranes to which these are attached at each end, the aerial vibrations passing down the meatus are transformed into corresponding vibrations of the fluids of the inner ear. The vibrations of the perilymph passing up the scala vestibuli, and down the scala tympani, reach at last the membrane covering the fenestra rotunda and throw this into vibration; and as a matter of fact it has been observed that when the membrane of the fenestra ovalis moves inward, that of the fenestra rotunda moves outwards, and *vice versâ*.

The vibrations of the perilymph thus produced will affect the endolymph, and this the hairs, and so the auditory epithelium of the labyrinth and cochlea; by which, finally, the auditory nerves will be excited.

22. The characters of the vibration of a membrane, and the readiness with which it takes up or responds to, aerial vibrations reaching it, are largely modified by its degree of tension; the membrane acts differently when it is tightly stretched from what it does when it is loose. Now, within the cavity of the tympanum are two small, but relatively strong muscles. One, called the *stapedius*, passes from the floor of the tympanum to the foot of the stapes and the orbicular bone, the other, the *tensor tympani*, from the front wall of the drum to the malleus. Each of the muscles when it contracts tightens the membrane to which it is thus indirectly attached, the tensor tympani, the membrane of the drum, and the stapedius, the membrane of the fenestra ovalis. The effect of thus tightening the membrane is probably to restrict the vibrations of the membrane, at least as far as concerns grave, or low-pitched

[1] Owing to certain characters in the attachment of the stapes to the membrane of the fenestra ovalis on the one hand, and to the os orbiculare on the other, the movements of the foot of the stapes in the fenestra ovalis are somewhat peculiar: but the details of these as well as the functions of the peculiar articulation of the incus with the malleus, have, for simplicity's sake, been omitted.

sounds; but the complete action of these muscles is too intricate to be dwelt on here.

23. The outer extremity of the external meatus is surrounded by the *concha* or external ear (*Co.* Fig. 69), a broad, peculiarly-shaped, and for the most part cartilaginous plate, the general plane of which is at right angles with that of the axis of the auditory opening. The concha can be moved by most animals and by some human beings in various directions by means of muscles, which pass to it from the side of the head.

24. The manner in which the complex apparatus now described intermediates between the physical agent, which is the primary cause of the sensation of sound, and the nervous expansion, the affection of which alone can excite that sensation, must next be considered.

All bodies which produce sound are in a state of vibration, and they communicate the vibrations of their own substance to the air with which they are in contact and thus throw that air into waves, just as a stick waved backwards and forwards in water throws the water into waves.

The aërial waves, produced by the vibrations of sonorous bodies, in part enter the external auditory passage, and in part strike upon the concha of the external ear and the outer surface of the head. It may be that some of the latter impulses are transmitted through the solid structure of the skull to the organ of hearing; but before they reach it they must, under ordinary circumstances, have become so scanty and weak, that they may be left out of consideration.

The aërial waves which enter the meatus all impinge upon the membrane of the drum and set it vibrating, stretched membranes, especially such as have the form and characters of the tympanic membrane, taking up vibrations from the air with great readiness.

25. The vibrations thus set up in the membrane of the tympanum are communicated, in part, to the air contained in the drum of the ear, and, in part, to the malleus, and thence to the other auditory ossicles.

The vibrations communicated to the air of the drum impinge upon the inner wall of the tympanum, on the

greater part of which, from its density, they can produce very little effect. Where this wall is formed by the membrane of the *fenestra rotunda* the communication of motion must necessarily be greater. All these vibrations, however, may probably be neglected.

The vibrations which are communicated to the malleus and the chain of ossicles may be of two kinds: vibrations of the particles of the bones, and vibrations of the bones as a whole. If a beam of wood, freely suspended, be very gently scratched with a pin, its particles will be thrown into a state of vibration, as will be evidenced by the sound given out, but the beam itself will not be visibly moved. Again, if a strong wind blow against the beam, it will swing bodily, without any vibrations of its particles among themselves. On the other hand, if the beam be sharply struck with a hammer, it will not only give out a sound, showing that its particles are vibrating, but it will also swing, from the impulse given to its whole mass.

Under the last-mentioned circumstances, a blind man standing near the beam would be conscious of nothing but the sound, the product of molecular vibration, or invisible oscillation of the particles of the beam; while a deaf man in the same position would be aware of nothing but the visible oscillation of the beam as a whole.

26. Thus, to return to the chain of auditory ossicles, while it may be supposed that, when the membrane of the drum vibrates, these may be set vibrating both as a whole and in their particles, the question arises whether it is the large vibrations, or the minute ones, which make themselves obvious to the auditory nerve, which is in the position of our deaf, or blind, man.

The evidence is distinctly in favour of the conclusion, that it is the vibrations of the bones, as a whole, which are the chief agents in transmitting the impulses of the aërial waves.

For, in the first place, the disposition of the bones and the mode of their articulation are very much against the transmission of molecular vibrations through their substance, but, on the other hand, are extremely favourable to their vibration *en masse*. The long processes of the malleus and incus swing, like a pendulum, upon the axis furnished by the short processes of these bones; while

the mode of connection of the incus with the stapes, and of the latter with the membrane of the fenestra ovalis, allows the foot plate of that bone free play, inwards and outwards. In the second place, the total length of the chain of ossicles is very small compared with the length of the waves of audible sounds, and physical considerations teach us that in a like thin rod, similarly capable of swinging *en masse*, the minute molecular vibrations would be inappreciable. Thirdly, direct experiments, such as attaching to the stapes of a dissected ear, a light style, the movements of which are recorded on a travelling smoked glass plate or in some other way, show that the chain of ossicles does actually vibrate as a whole, and at the same rate as the membrane of the drum, when aërial vibrations strike upon the latter.

27. Thus, there is reason to believe that when the tympanic membrane is set vibrating, it causes the process of the malleus, which is fixed to it, to swing at the same rate; the head of the malleus consequently turns through a small arc on its pivot, the slender process. But, as stated in § 21, the turning of the head of the malleus involves the simultaneous turning of the head of the incus upon its pivot, the short process. In consequence the long process of the incus also swings at the same rate. The length of the long process of the incus, measured from the axis, on which the two bones turn, is less than that of the handle of the malleus; hence the end of it moves through a smaller space. The arc through which it moves has been estimated as being equal to about two-thirds of that described by the handle of the malleus. The extent of the push is thereby somewhat diminished, but the force of the push is proportionately increased; in so confined a space this change is advantageous. The long process of the incus, however, is so fixed to the stapes, and the stapes so attached to the membrane of the fenestra ovalis, that the incus cannot vibrate without throwing into vibrations, to a corresponding extent and at the same rate, the membrane of the fenestra ovalis.[1] But every vibration, every pull and push, imparts a corresponding set of shakes to the perilymph, which fills the bony labyrinth and cochlea, external to the membranous labyrinth and

[1] See foot-note, p. 231.

canalis cochlearis. These shakes are communicated to the endolymph in the latter chambers, and, by the help of the modified auditory epithelium described above, stimulate the delicate endings of the vestibular and cochlear divisions of the auditory nerve.

28. We do not at present know what kind of changes the vibrations of the endolymph give rise to in the epithelial cells of the maculæ of the utriculus and sacculus, of the crests of the ampullæ, and of the organ of Corti; nor do we at present know the exact way in which the changes thus set up in these epithelial cells are able to excite the terminal filaments of the auditory nerve. But there can be no doubt of the fact that the elaborate apparatus of the cochlea and the simpler apparatus of the labyrinth are able to translate, so to speak, the sonorous vibrations which reach them into stimulations of nerve fibres, the molecular changes of which are transmitted along the auditory nerve as auditory nervous impulses. Passing along the auditory nerve, these molecular changes, these nervous impulses, reach certain parts of the brain, the exact situation of which is at present a matter of conjecture, and there in turn set up those molecular disturbances of nervous matter which form the immediate cause of the states of feeling called "sounds." Thus the auditory nerve may be said, and a similar statement may be made in the case of the other nerves of special sensations, to be provided with two "end-organs." There is the *peripheral end-organ* (the apparatus of the cochlea and labyrinth), by which the physical agent is enabled to excite the sensory nerve-fibres; and there is the *central end-organ*, in the brain, in which the nervous impulses of the sensory nerve excite the special state of feeling which we call the special sensation. The central end-organ of hearing is often spoken of as the auditory sensorium.

Between the sounding body and the actually hearing a sound there is a chain of events of different kinds. There are the vibrations started by the sounding body, and passing through the air, the tympanum, the perilymph, and the endolymph; these are all of one order. Then there are the changes in the peripheral end-organ, in the apparatus of the cochlea and labyrinth; these are of another order. Then follow the molecular disturbances

travelling along the auditory nerve; these are of still another order. Lastly, there are the changes in the central end-organ, in the brain; these, though resembling the preceding in so far as they are changes of nervous matter, are yet of still another order, and probably comprise in themselves a whole series of events, the consequence of the last of which is the sensation of sound.

29. The differences between the functions of the membranous labyrinth (to which the vestibular nerve is distributed) and those of the cochlea are not quite certainly made out, but the following view has been suggested:—

Every sound consists, as we have seen, of vibrations. Sometimes the vibrations are repeated with great regularity; and sounds, in which the regular recurrence of the same vibrations is conspicuous, are called "musical sounds." Sometimes no regular repetition of vibrations can be recognised; the sound consists of vibrations, few of which are like each other, and which fall irregularly on the ear; such sounds are called "noises."

When we listen to musical sounds, each set of regularly repeated vibrations generates in the central end-organ a particular kind of sensation which we call a *tone;* and the simultaneous or successive production of different tone-sensations gives rise in us to the feelings which we speak of as those of harmony or melody.

When we listen to a noise the vibrations generate sensations which are of a certain intensity, according to which we call the noise slight or great, low or loud, and which also have certain characters by which we recognise the kind of noise; but the sensations have not the qualities of tone-sensations, and do not give rise to feelings of melody or harmony.

And it has been suggested that the arrangements of the cochlea are such that musical sounds are enabled to excite the cochlear nerve, and to generate in the central end-organ connected with it sensations of tone; while the arrangements of the labyrinth and the central end-organ of the vestibular nerve are such as to be readily affected by noises.

Such a view is not without difficulties; but the following considerations render it probable that the cochlea at least is adapted for the appreciation of musical sounds.

30. A pure musical sound consists of a series of vibrations repeated with exact regularity, the number of vibrations occurring in a given time, *e.g.* in a second, determining what is called the pitch of the " note." But ordinary musical sounds are, for the most part, not simple, consisting of one set of vibrations, but compound, consisting of several sets of vibrations occurring together; in these musicians distinguish one set, called the *fundamental tone*, and other sets, varying in intensity or loudness, called *overtones*.

A tuning-fork, when set vibrating, vibrates with a given rapidity; and the note given out is determined by the rapidity of the vibration, by the number of vibrations repeated, for instance, in a second; hence every tuning-fork has its own proper note. Now, a tuning-fork will be set vibrating if its own particular note be sounded in its neighbourhood, but not if other notes be sounded. Hence, when a pure musical note is sounded close to a number of tuning-forks of different pitch, only that tuning-fork the pitch of which is the same as that of the note sounded is set vibrating; the others remain motionless. When an ordinary musical sound, such as a note sung by the human voice, is produced among such a group of tuning-forks, several are set vibrating; one of these corresponds to the fundamental tone, and the others to the various overtones of the sound. Similarly, if the top of a piano be lifted up or removed, and any one sings into the wires with sufficient loudness, a note, such as the tenor C, a number of the wires will be set vibrating, one corresponding to the fundamental tone, and the others to the overtones.

If we were to imagine an immense number of tuning-forks, each vibrating at different periods, so arranged that each fork, when vibrating, in some way or other stimulated or excited a minute delicate nerve-filament attached to it, it is obvious that a musical sound uttered near these tuning-forks would set a certain number of them into vibration, some more forcibly than others, and that in consequence a certain number, and a certain number only, of the delicate nerve filaments would be excited, and that to various degrees; and thus a particular series of nervous impulses, the counterpart as it were of the musical sound

with its fundamental tone and overtones, would be transmitted along the nerve filaments to the brain.

And it is suggested that the basilar membrane of the cochlea, consisting as it does of thousands of fibres stretching across from the inside to the outside (from left to right in Fig. 68), with its thousands of epithelial cells and rods of Corti lying upon it, represents, as it were, an assemblage of thousands of tuning-forks of various rates of vibration, with a separate nerve filament attached to each. So that, when a number of vibrations of different periods, such as constitutes an ordinary musical sound, are transmitted by the tympanum to the cochlea, these as they sweep along the canalis cochlearis throw into sympathetic movement those parts, and those parts only, of the basilar membrane with their overlying epithelium and rods of Corti, whose periods of vibration correspond to their own vibrations, and thus excite certain nerve filaments, and these only. It is this excitement of a group of nerve filaments, some more intensely than others, which reaching the brain gives rise to the sensation which we associate with the particular musical sound.

As has been already stated, we know very little definitely about the position in the brain of, and still less about the nature of, the auditory sensorium or central end-organ of the auditory nerve; but it may be conceived that each filament of the cochlear nerve is connected with a particular portion of the nervous matter of the central end-organ, in such a way that the molecular movements of one of these particular portions of nervous matter, brought about by a molecular disturbance reaching it through its appropriate filament, produces a psychical effect of one kind only, more or less intense it may be, but still always of one kind. If this be so, each cochlear fibre or filament may be considered as being provided with two end-organs: one, peripheral, in the organ of Corti, capable of being set in motion by vibrations of one quality only; the other, central, in the brain, capable of producing a psychical effect of one quality only. It does not follow, however, that we are distinctly and separately conscious of the nervous disturbance in each central end-organ, it does not follow that we have as many distinct and separate kinds of

conscious sensation as there are peripheral and central end-organs, though how many such distinct kinds of sensation we may have we do not know. Just as the peripheral mechanism sifts out the several vibrations of which a musical sound is composed, and transmits them separately, so, by a reverse operation, the central mechanism probably pieces together the nervous disturbances of a number of central end-organs, and thus produces a sensation whose characters are determined by a combination of the nervous disturbances taking place in each end-organ.

Some such a view is indeed exceedingly probable; but it must be remembered that we do not at present at all understand the exact mechanism by which each particular vibration excites its corresponding nerve filament. The nerve filaments appear to end in the epithelial cells bearing short hairs, which lie on each side of the rods of Corti; and we may therefore conclude that these "hair-cells" have some share in producing the effect. But the whole matter is at present very obscure; the functions of the rods of Corti are particularly difficult to understand; for these do not seem in any way connected with the nerve filaments, and their movements can only affect the latter by influencing in some way the hair-cells.

31. The fibres of the cochlear nerve, or their endings in the brain itself, may be excited by internal causes, such as the varying pressure of the blood and the like: and in some persons such internal influences do give rise to veritable musical spectra, sometimes of a very intense character. But, for the appreciation of music produced external to us, we depend upon the organ of Corti being in some way or other affected by the vibrations of the fluids in the cochlea.

32. It has already been explained that the *stapedius* and *tensor tympani* muscles are competent to tighten the membrane of the fenestra ovalis and that of the tympanum, and it is probable that they come into action when the sonorous impulses are too violent, and would produce too extensive vibrations of these membranes. They may therefore be of use in moderating the effect of intense sound, in much the same way that, as we shall find, the

contraction of the circular fibres of the iris tends to moderate the effect of intense light in the eye ; they may however, have other purposes.

The function of the Eustachian tube is, probably, to keep the air in the tympanum, or on the inner side of the tympanic membrane, of about the same tension as that on the outer side, which could not always be the case if the tympanum were a closed cavity.

LESSON IX.

THE ORGAN OF SIGHT.

1. IN studying the organ of the sense of sight, the eye, it is needful to become acquainted, firstly, with the structure and properties of the sensory expansion in which the optic nerve, or nerve of sight, terminates; secondly, with the physical agent of the sensation; thirdly, with the intermediate apparatus by which the physical agent is assisted in acting upon the nervous expansion.

The ball, or globe, of the eye is a globular body, moving freely in a chamber, the *orbit*, which is furnished to it by the skull. The optic nerve, the root of which is in the brain, leaves the skull by a hole at the back of the orbit, and enters the back of the globe of the eye, not in the middle, but on the inner, or nasal, side of the centre. Having pierced the wall of the globe, it spreads out into a very delicate membrane, varying in thickness from $\frac{1}{80}$th of an inch to less than half that amount, which lines the hinder two-thirds of the globe, and is termed the *retina*. This retina is the only organ connected with sensory nervous fibres which can be affected, by any agent, in such a manner as to give rise to the sensation of light.

2. If the globe of the eye be cut in two, transversely, so as to divide it into an anterior and a posterior half, the retina will be seen lining the whole of the concave wall of the posterior half as a membrane of great delicacy, and, for the most part, of even texture and smooth surface. But almost exactly opposite the middle of the posterior

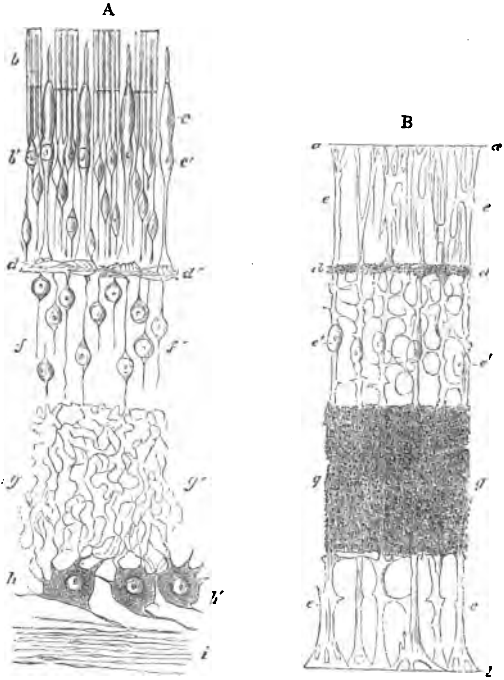

FIG. 72.—DIAGRAMMATIC VIEWS OF THE NERVOUS (A) AND THE CONNECTIVE (B) ELEMENTS OF THE RETINA, SUPPOSED TO BE SEPARATED FROM ONE ANOTHER.

A, the nervous structures—*b*, the rods; *c*, the cones; *b' c'*, the granules or nuclei of the outer layer, with which these are connected; *d d'*, interwoven very delicate nervous fibres, from which fine nervous filaments, bearing the inner granules or nuclei, *f f'*, proceed towards the inner surface; *g g'*, the continuation of these fine nerves, which become convoluted and interwoven with the processes of the nerve cells *h h'*; *i i*, the expansion of the fibres of the optic nerve. B, the connective tissue—*a a*, external limiting membrane; *e e*, radial fibres passing to the internal limiting membrane; *e' e'*, nuclei; *d d*, the intergranular layer; *g g*, the molecular layer; *l*, the inner limiting membrane.

(Magnified about 250 diameters.)

wall, it presents a slight circular depression of a yellowish hue, the *macula lutea*, or yellow spot (Fig. 73, *m.l.*; Fig. 76, 8″),—not easily seen, however, unless the eye be perfectly fresh,—and, at some distance from this, towards the inner, or nasal, side of the ball, is a radiating appearance, produced by the entrance of the optic nerve and the spreading out of its fibres into the retina.

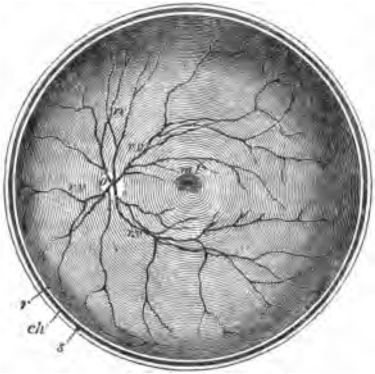

FIG. 73.—THE EYEBALL DIVIDED TRANSVERSELY IN THE MIDDLE LINE, AND VIEWED FROM THE FRONT.

s, sclerotic; *ch*, choroid, seen in section only.
r, the cut edges of the retina; *v.v*, vessels of the retina springing from *o*, the optic nerve or blind spot; *m.l*, the yellow spot, the darker spot in its middle being the fovea centralis.

3. A very thin vertical slice of the retina, in any region except the yellow spot and the entrance of the optic nerve, may be resolved into the structures represented separately in Fig. 72. The one of these (A) occupies the whole thickness of the section, and comprises its essential, or nervous, elements. The outer[1] fourth, or

[1] In the following account of the retina, the parts are described in relation to the eyeball. Thus, that surface of the retina which touches the vitreous humour, and so is nearer the centre of the eyeball, is called the *inner* surface; and that surface which touches the choroid coat is called the *outer* surface. And so with the structures between these two surfaces; that which is called inner is nearer the vitreous humour, and that which is called outer

rather less, of the thickness of these consists of a vast multitude of minute, either rod-like, or conical bodies, ranged side by side, perpendicularly to the plane of the retina. This is the *layer of rods and cones* (*b c*). From the front ends or bases of the rods and cones very delicate fibres pass, and in each is developed a granule-like or nucleus-like body (*b′ c′*), which forms a part of what has been termed the *outer layer of granules*, or *outer nuclear layer*. It is probable that these fibres next pass into and indeed form the close meshwork of very delicate nervous fibres which is seen at *d d′* (Fig. 72, A). From the inner surface of this meshwork other fibres proceed, containing a second set of granules or nuclei, which forms the *inner granular layer*, or *inner nuclear layer* (*f f′*). Inside this layer is a stratum of convoluted fine nervous fibres (*g g′*)—and inside this again are numerous nerve-cells (*h h′*). Processes of these nerve-cells extend, on the one hand, into the layer of convoluted nerve-fibres; and on the other are probably continuous with the stratum of fibres of the optic nerve (*i*).

These delicate nervous structures are supported by a sort of framework of connective tissue of a peculiar kind (B), which extends from an *inner or anterior limiting membrane* (*l*), which bounds the retina and is in contact with the vitreous humour, to an *outer* or *posterior limiting membrane*, which lies at the inner ends, or bases, of the rods and cones near the level of *b′ c′* in A. Thus the framework falls short of the nervous substance of the retina, and the rods and cones lie altogether outside of it, wholly unsupported by any connective tissue. They are, however, as we shall see, imbedded in the layer of pigment on which the retina rests (§ 16).

The fibres of the optic nerve spread out between the limiting membrane (*l*) and the nerve-cells (*h′*), and the vessels which enter along with the optic nerve ramify between the two limiting membranes, most of them running between the inner limiting membrane and the inner nuclear layer (*f f′*). Thus, not only the nervous fibres, but the vessels, are placed altogether in front of the rods and cones.

is nearer the choroid coat. Sometimes *anterior*, or front, is used instead of inner, and *posterior* instead of outer.

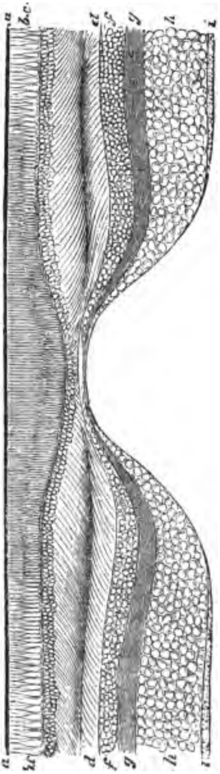

FIG. 74.—A DIAGRAMMATIC SECTION OF THE MACULA LUTEA, OR YELLOW SPOT.

a a, the pigment of the choroid; *b c*, rods and cones; *d d*, outer granular or nuclear layer; *ff*, inner granular or nuclear layer; *gg*, molecular layer; *h h*, layer of nerve cells; *i i*, fibres of the optic nerve.

(Magnified about 60 diameters.)

At the entrance of the optic nerve itself, the nervous fibres predominate, and the rods and cones are absent. In the yellow spot, on the contrary, the cones are abundant and close set, becoming at the same time longer and more slender, while rods are scanty, and are found only towards its margin. The layer of fibres of the optic nerve disappears, and all the other layers, except that of the cones, become extremely thin in the centre of the *macula lutea* (Fig. 74).

4. The most notable property of the retina is its power of converting the vibrations of ether, which constitute the physical basis of light, into a stimulus to the fibres of the optic nerve. The central ends of these fibres are connected with certain parts of the brain which constitute the *visual sensorium*, just as other parts, as we have seen, constitute the auditory sensorium. The molecular disturbances set up in the fibres of the optic nerve are transmitted to the substance of the visual sensorium, and produce changes in the latter, giving rise to the state of feeling which we call a sensation of light.

The sensation of light, it must be understood, is the work of the visual sensorium, not of the retina; for, if an eye be destroyed, pinching, galvanizing, or otherwise irritating the optic nerve, will still excite the sensation of light, because it throws the fibres of the optic nerve into activity; and their activity, however produced, brings about in the visual sensorium certain changes which give rise to the sensation of light.

Light, falling directly on the optic nerve, does not excite it; the fibres of the optic nerve, in themselves, are as blind as any other part of the body. But just as the peculiar hair cells of the labyrinth, and the organ of Corti of the cochlea, are contrivances for converting the delicate vibrations of the perilymph and endolymph into impulses which can excite the auditory nerves, so the structures in the retina appear to be adapted to convert the infinitely more delicate pulses of the luminiferous ether into stimuli of the fibres of the optic nerve.

5. The sensibility of the different parts of the retina to light varies very greatly. The point of entrance of the optic nerve is absolutely blind, as may be proved by a very simple experiment. Close the left eye, and look

steadily with the right at the cross on the page, held at ten or twelve inches' distance.

✠ ●

The black dot will be seen quite plainly, as well as the cross. Now, move the book slowly towards the eye, which must be kept steadily fixed upon the cross; at a certain point the dot will disappear, but, as the book is brought still closer, it will come into view again. It results from optical principles that, in the first position of the book, the image of the dot falls between that of the cross (which throughout lies upon the yellow spot) and the

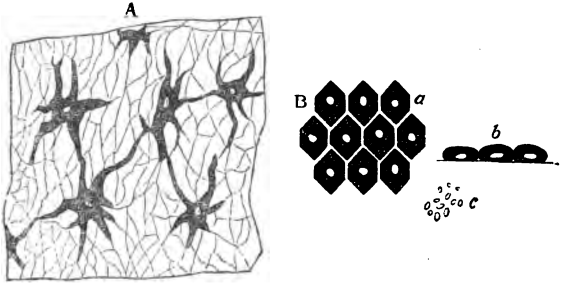

FIG. 75.—PIGMENT CELLS FROM THE CHOROID COAT.

A, branched pigment cells from the deep layer.
B, pigment epithelium. *a*, seen in face; *b*, seen in profile; *c*, pigment granules.

entrance of the optic nerve: while, in the second position, it falls on the entrance of the optic nerve itself; and, in the third, inside that point. So long as the image of the spot rests upon the entrance of the optic nerve, it is not perceived, and hence this region of the retina is called the *blind spot*. The experiment proves that the vibrations of the ether are not able to excite the fibres of the optic nerve itself.

6. The impression made by light upon the retina not only remains during the whole period of the direct action of the light, but has a certain duration of its own, however short the time during which the light itself lasts. A

flash of lightning is, practically, instantaneous, but the sensation of light produced by that flash endures for an appreciable period. It is found, in fact, that a luminous impression lasts for about one-eighth of a second; whence it follows, that if any two luminous impressions are separated by a less interval, they are not distinguished from one another.

For this reason a "Catherine-wheel," or a lighted stick turned round very rapidly by the hand, appears as a circle of fire; and the spokes of a coach wheel at speed are not separately visible, but only appear as a sort of opacity, or film, within the tire of the wheel.

7. The excitability of the retina is readily exhausted. Thus, looking at a bright light rapidly renders the part of the retina on which the light falls, insensible; and on looking from the bright light towards a moderately-lighted surface, a dark spot, arising from a temporary blindness of the retina in this part, appears in the field of view. If the bright light be of one colour, the part of the retina on which it falls becomes insensible to rays of that colour, but not to the other rays of the spectrum. This is the explanation of the appearance of what are called *complementary colours.* For example, if a bright red wafer be stuck upon a sheet of white paper, and steadily looked at for some time with one eye, when the eye is turned aside to the white paper a greenish spot will appear, of about the size and shape of the wafer. The red image has, in fact, fatigued the part of the retina on which it fell for red light, but has left it sensitive to the remaining coloured rays of which white light is composed. But we know that if from the variously coloured rays which make up the spectrum of white light we take away all the red rays, the remaining rays together make up a sort of green. So that, when white light falls upon this part, the red rays in the white light having no effect, the result of the operation of the others is a greenish hue. If the wafer be *green,* the *complementary image*, as it is called, is *red.*

8. Most people agree very closely as to differences between different colours and different parts of the spectrum. But there are exceptions. Thus a certain number of persons see very little difference between the colour which most people call red, and that which most

people call green: Such *colour-blind* persons are unable to distinguish between the leaves of a cherry-tree and its fruit by the colour of the two; they are only aware of a difference of shape between the two. Cases of this "red-blindness" or "red-green" blindness are not uncommon; but another form of colour blindness in which blue and yellow cannot be distinguished from each other is much more rare; and though it has been asserted that persons have been found, who were *wholly* colour blind, *i.e.* to whom all colours were mere shades of one tint, such cases are not beyond doubt.

This peculiarity of colour-blindness is simply unfortunate for most people, but it may be dangerous if unknowingly possessed by railway guards or sailors. It probably arises either from a defect in the retina, which renders that organ unable to respond to different kinds of luminous vibrations, and consequently insensible to red, yellow, or other rays, as the case may be; or the fault may lie in the visual sensorium itself.

9. The sensation of light may be excited by other causes than the impact of the vibrations of the luminiferous ether upon the retina. Thus, an electric shock sent through the eye or through the optic nerve gives rise to the appearance of a flash of light: and pressure on any part of the retina produces a luminous image, which lasts as long as the pressure, and is called a *phosphene*. If the point of the finger be pressed upon the outer side of the ball of the eye, the eyes being shut, a luminous image—which, in my own case, is dark in the centre, with a bright ring at the circumference (or, as Newton described it, like the "eye" in a peacock's tail-feather)—is seen; and this image lasts as long as the pressure is continued. Most persons, again, have experienced the remarkable display of subjective fireworks which follows a heavy blow about the region of the eyes, produced by a fall from a horse, or by other methods well known to English youth.

It is doubtful, however, whether these effects of pressure, or shock, really arise from the excitation of the retina proper, or whether they are not rather the result of the violence done to the fibres of the optic nerve apart from the retina.

10. The last paragraph raises a distinction between

the "fibres of the optic nerve" and the "retina" which may not have been anticipated, but which is of much importance.

We have seen that the fibres of the optic nerve ramify in the inner fourth of the thickness of the retina, while the layer of rods and cones forms its outer fourth. The light, therefore, must fall first upon the fibres of the optic nerve, and, only after traversing them, can it reach the rods and cones. Consequently, if the fibrillæ of the optic nerve themselves are capable of being affected by light, the rods and cones can only be some sort of supplementary optical apparatus. But, in fact, it is the rods and cones which are affected by light, while the fibres of the optic nerve are themselves insensible to it. The evidence on which this statement rests is:—

a. The blind spot is full of nervous fibres, but has no cones or rods.

b. The yellow spot, where the most acute vision is situated, is full of close-set cones, but has no nerve fibres.

c. If one goes into a dark room with a single small bright candle, and, looking towards a dark wall, moves the light up and down, close to the outer side of one eye, so as to allow the light to fall very obliquely into the eye, one of what are called *Purkinje's figures* is seen. This is a vision of a series of diverging, branched, dark, sometimes reddish, lines on an illuminated field, and in the interspace of two of these lines is a sort of cup-shaped disk. The branched lines are the images of shadows thrown by the retinal blood-vessels, and the disk is that of the shadow thrown by the edge of the yellow spot. As the candle is moved up and down, the lines shift their position, as shadows do when the light which throws them changes its place.

Now, as the light falls on the inner face of the retina, and the images of the vessels to which it gives rise shift their position as it moves, whatever constitutes the end-organ, through which light stimulates the fibres of the optic nerve, must needs lie on the other, or outer, side of the vessels. But the fibres of the optic nerve lie among the vessels, and the only retinal structures which lie outside them are the nuclear layers and the rods and cones.

d. Just as, in the skin, there is a limit of distance within which two points give only one impression, so there is a minimum distance by which two points of light falling on the retina must be separated in order to appear as two. And this distance corresponds pretty well with the diameter of a cone.

11. The impact of the ethereal vibrations upon the sensory expansion, or *essential* part of the visual apparatus alone, is sufficient to give rise to all those *feelings*, which we term sensations of *light* and of *colour*, and further to that feeling of *outness* which accompanies all visual sensation. But, if the retina had a simple transparent covering, the vibrations radiating from any number of distinct luminous points in the external world would affect all parts of it equally, and therefore the feeling aroused would be that of a generally diffused luminosity. There would be no separate feeling of light for each separate radiating point, and hence no correspondence between the visual sensations and the radiating points which aroused them.

It is obvious that, in order to produce this correspondence, or, in other words, to have distinct vision, the essential condition is, that distinct luminous points in the external world shall be represented by distinct feelings of light. And since, in order to produce these distinct feelings, vibrations must impinge on separate rods or cones, or at least on separate parts of the retina, it follows that, for the production of distinct vision, some apparatus must be interposed between the retina and the external world, by the action of which, distinct luminous points in the latter shall be represented by corresponding points of light on the retina.

In the eye of man and of the higher animals, this *accessory* apparatus of vision is represented by structures which, taken together, act as a biconvex lens, composed of substances which have a much greater refractive power than the air by which the eye is surrounded; and which throw upon the retina luminous points, which correspond in number, and in position relatively to one another, with those luminous points in the external world from which ethereal vibrations proceed towards the eye. The luminous points thus thrown upon the retina form a picture

of the external world—a picture being nothing but lights and shadows, or colours, arranged in such a way as to correspond with the disposition of the luminous parts of the object represented, and with the qualities of the light which proceeds from them.

12. That a biconvex lens is competent to produce a picture of the external world on a properly arranged screen is a fact of which every one can assure himself by simple experiments. An ordinary spectacle glass is a transparent body denser than the air, and convex on both sides. If this *lens* be held at a certain distance from a screen or wall in a dark room, and a lighted candle be placed on the opposite side of it, it will be easy to adjust the distances of candle, lens, and wall, in such a manner that an image of the flame of the candle, upside down, shall be thrown upon the wall.

The spot on which the image is formed is called a *focus*. If the candle be now brought nearer to the lens, the image on the wall will enlarge, and grow blurred and dim, but it may be restored to brightness and definition by moving the lens further from the wall. But if, when the new adjustment has taken place, the candle be moved away from the lens, the image will again become confused, and to restore its clearness, the lens will have to be brought nearer the wall.

Thus a convex lens forms a distinct picture of luminous objects, but only at the focus on the side of the lens opposite to the object; and that focus is nearer when the object is distant, and further off when it is near.

13. Suppose, however, that, leaving the candle unmoved, a lens with more convex surfaces is substituted for the first, the image will be blurred, and the lens will have to be moved nearer the wall to give it definition. If, on the other hand, a lens with less convex surfaces is substituted for the first, it must be moved further from the wall to attain the same end.

In other words, other things being alike, the more convex the lens the nearer its focus; the less convex, the further off its focus.

If the lens were made of some extensible, elastic substance, like india-rubber, pulling it at the circumference would render it flatter, and thereby lengthen its focus;

while, when let go again, it would become more convex, and of shorter focus.

Any material more refractive than the medium in which it is placed, if it have a convex surface, causes the rays of light which pass through the less refractive medium to that surface to converge towards a focus. If a watch-glass be fitted into one side of a box, and the box be then filled with water, a candle may be placed at such a distance outside the watch-glass that an image of its flame shall fall on the opposite wall of the box. If, under these circumstances, a doubly convex lens of glass were introduced into the water in the path of the rays, it would act (though less powerfully than if it were in air) in bringing the rays more quickly to a focus, because glass refracts light more strongly than water does.

A *camera obscura* is a box, into one side of which a lens is fitted, so as to be able to slide backwards and forwards, and thus throw on the screen at the back of the box distinct images of bodies at various distances off. Hence the arrangement just described might be termed a *water camera.*

14. The accessory organs, by means of which the physical agent of vision, light, is enabled to act upon the expansion of the optic nerve, comprise three kinds of apparatus: (*a*) a "water camera," the eyeball; (*b*) muscles for moving the eyeball; (*c*) organs for protecting the eyeball, viz. the eyelids, with their lashes, glands, and muscles; the conjunctiva; and the lachrymal gland and its ducts.

The *eyeball* is composed, in the first place, of a tough, firm, spheroidal case consisting of fibrous or connective tissue, the greater part of which is white and opaque, and is called the *sclerotic* (Fig. 76, 2). In front, however, this fibrous capsule of the eye, though it does not change its essential character, becomes transparent, and receives the name of the *cornea* (Fig. 76, 1). The corneal portion of the case of the eyeball is more convex than the sclerotic portion, so that the whole form of the ball is such as would be produced by cutting off a segment from the front of a spheroid of the diameter of the sclerotic, and replacing this by a segment cut from a smaller, and consequently more convex, spheroid.

15. The corneo-sclerotic case of the eye is kept in shape by what are termed the *humours*—watery or semi-fluid substances, one of which, the *aqueous* humour (Fig. 76, 7′),

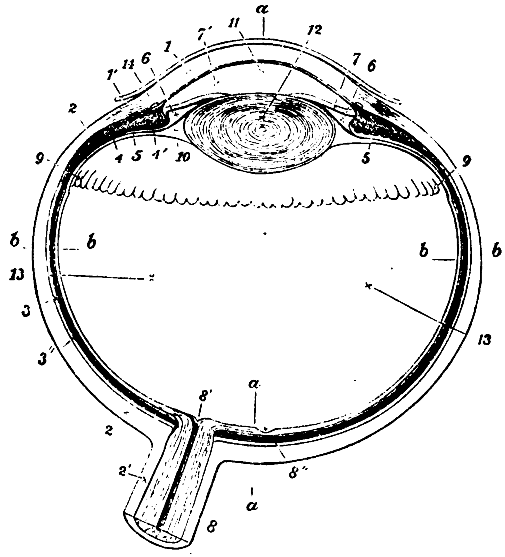

FIG. 76.—HORIZONTAL SECTION OF THE EYEBALL.

1, cornea; 1′, conjunctiva; 2, sclerotic; 2′, sheath of optic nerve; 3, choroid; 3″; rods and cones of the retina; 4, ciliary muscle; 4′, circular portion of ciliary muscle; 5, ciliary process; 6, posterior chamber between; 7, the iris and the suspensory ligament; 7′, anterior chamber; 8, artery of retina in the centre of the optic nerve; 8′, centre of blind spot; 8″, macula lutea; 9, ora serrata (this is of course not seen in a section such as this, but is introduced to show its position); 10, space behind the suspensory ligament (canal of Petit); 12, crystalline lens; 13, vitreous humour; 14, marks the position of the ciliary ligament; *a*, optic axis, (in the actual eye of which this is an exact copy, the yellow spot happened, curiously enough, not to be in the optic axis); *b*, line of equator of the eyeball.

which is hardly more than water holding a few organic and saline substances in solution, distends the corneal chamber of the eye, while the other, the *vitreous*

(Fig. 76, 13), which is rather a delicate jelly than a regular fluid, keeps the sclerotic chamber full.

The two humours are separated by the very beautiful, transparent, doubly-convex *crystalline lens* (Fig. 76, 12), denser, and capable of refracting light more strongly than either of the humours. The crystalline lens is composed of fibres having a somewhat complex arrangement, and is highly elastic. It is more convex behind than in front, and it is kept in place by a delicate, but at the same time strong membranous frame or *suspensory ligament*, which extends from the edges of the lens to what are termed the *ciliary processes* of the choroid coat (Figs. 76, 5, and 77, *c*). In the ordinary condition of the eye this ligament is kept tense, *i.e.* is stretched pretty tight, and the front part of the lens is consequently flattened.

16. This *choroid coat* (Fig. 76, 3) is a highly vascular membrane, in close contact with the sclerotic externally, and lined, internally, by a layer of small polygonal bodies containing much pigmentary matter, called *pigment cells* (Fig. 75). These pigment cells are separated from the vitreous humour by the retina only. The rods and cones of the latter are in immediate contact with them; indeed these cells may perhaps, be more truly considered as part of the retina than as part of the choroid. The choroid lines every part of the sclerotic, except just where the optic nerve enters it at a point below, and to the inner side of the centre of the back of the eye; but when it reaches the front part of the sclerotic, its inner surface becomes raised up into a number of longitudinal ridges, with intervening depressions, like the crimped frills of a lady's dress, terminating within and in front by rounded ends, but passing, externally, into the iris. These ridges, which when viewed from behind seem to radiate on all sides from the lens (Figs. 77, *c*, and 76, 5), are the above-mentioned ciliary processes.

17. The *iris* itself (Figs. 76, 7, and 77, *a*, *b*) is, as has been already said, a curtain with a round hole in the middle, provided with circular and radiating unstriped muscular fibres, and capable of having its central aperture enlarged or diminished by the action of these fibres, the contraction of which, unlike that of other unstriped muscular fibres, is extremely rapid. The edges of the iris are

firmly connected with the capsule of the eye, at the junction of the cornea and sclerotic, by the connective tissue which enters into the composition of the so-called *ciliary ligament.* Unstriped muscular fibres, having the same attachment in front, spread backwards on to the outer surface of the choroid, constituting the *ciliary muscle* (Fig. 76, 4). If these fibres contract, it is obvious that they will pull the choroid forwards ; and as the frame, or suspensory ligament of the lens, is connected with the ciliary processes (which simply form the anterior termination of the choroid), this pulling forward of the choroid comes to the same thing as a relaxation of the tension of

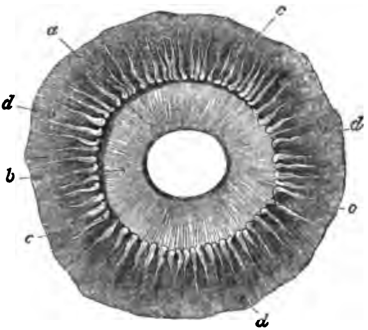

FIG. 77.—VIEW OF FRONT HALF OF THE EYEBALL SEEN FROM BEHIND.
a, circular fibres ; *b*, radiating fibres of the iris ; *c*, ciliary processes ; *d*, choroid. The crystalline lens has been removed.

that suspensory ligament, which, as I have just said, is in an ordinary condition stretched somewhat tight, keeping the front of the lens flattened.

The iris does not hang down perpendicularly into the space between the front face of the crystalline lens and the posterior surface of the cornea, which is filled by the aqueous humour, but applies itself very closely to the anterior face of the lens, so that hardly any interval is left between the two (Figs. 76 and 78).

The retina, as we have seen, lines the interior of the eye, being placed between the choroid and vitreous humour,

its rods and cones being imbedded in the pigment epithelium lining the former, and its inner limiting membrane touching the latter.

About a third of the distance back from the front of the eye the retina seems to end in a wavy border called the *ora serrata* (Fig. 76, 9), and in reality the nervous elements of the retina do end here, having become considerably reduced before this line is reached. Some of the connective tissue elements however pass on as a delicate kind of membrane at the back of the ciliary processes towards the crystalline lens.

18. The eyeball, the most important constituents of which have now been described, is, in principle, a camera of the kind described above—a water camera. That is to say, the sclerotic answers to the box, the cornea to the watch-glass, the aqueous and vitreous humours to the water filling the box, the crystalline to the glass lens, the introduction of which was imagined. The back of the box corresponds with the retina.

But further, in an ordinary camera obscura, it is found desirable to have what is termed a *diaphragm* (that is, an opaque plate with a hole in its centre) in the path of the rays, for the purpose of moderating the light and cutting off the marginal rays which, owing to certain optical properties of spheroidal surfaces, give rise to defects in the image formed at the focus.

In the eye, the place of this diaphragm is taken by the iris, which has the peculiar advantage of being self-regulating: dilating its aperture, and admitting more light when the light is weak; but contracting its aperture and admitting less light when the illumination is strong.

19. In the water camera, constructed according to the description given above, there is the defect that no provision exists for adjusting the focus to the varying distances of objects. If the box were so made that its back, on which the image is supposed to be thrown, received distinct images of very distant objects, all near ones would be indistinct. And if, on the other hand, it were fitted to receive the image of near objects, at a given distance, those of either still nearer, or more distant, bodies would be blurred and indistinct. In the ordinary camera this

difficulty is overcome by sliding the lenses in and out, a process which is not compatible with the construction of our water camera. But there is clearly one way among many, in which this adjustment might be effected—namely, by changing the glass lens; putting in a less convex one when more distant objects had to be pictured, and a more convex one when the images of nearer objects were to be thrown upon the back of the box.

But it would come to the same thing, and be much more convenient, if, without changing the lens, one and the same lens could be made to alter its convexity. This is what actually is done in the adjustment of the eye to distances.

20. The simplest way of experimenting on the *adjustment* or *accommodation of the eye* is to stick two stout needles upright into a straight piece of wood, not exactly, but nearly in the same straight line, so that, on applying the eye to one end of the piece of wood, one needle (*a*) shall be seen about six inches off, and the other (*b*) just on one side of it at twelve inches or more distance.

If the observer look at the needle *b*, he will find that he sees it very distinctly, and without the least sense of effort; but the image of *a* is blurred and more or less double. Now let him try to make this blurred image of the needle *a* distinct. He will find he can do so readily enough, but that the act is accompanied by a sense of effort somewhere in the eye. And in proportion as *a* becomes distinct, *b* will become blurred. Nor will any effort enable him to see *a* and *b* distinctly at the same time.

21. Multitudes of explanations have been given of this remarkable power of adjustment; but the true solution of the problem has been gained by the accurate determination of the nature of the changes in the eye which accompany the act. When the flame of a taper is held near, and a little on one side of, a person's eye, any one looking into the eye from a proper point of view, will see three images of the flame, two upright and one inverted. One upright figure is reflected from the front of the cornea, which acts as a convex mirror. The second proceeds from the front of the crystalline lens, which has the same effect; while the inverted image

proceeds from the posterior face of the lens, which, being convex backwards, is, of course, concave forwards, and acts as a concave mirror.

Suppose the eye to be steadily fixed on a distant object, and then adjusted to a near one in the same line of vision, the position of the eyeball remaining unchanged. Then the upright image reflected from the surface of the cornea, and the inverted image from the back of the lens, will remain unchanged, though it is demonstrable that their size or apparent position must change if either the cornea, or the back of the lens, alter either their form or their position. But the second upright image, that reflected by the front face of the lens, does change both its size and its position; it comes forward and grows smaller, proving that the front face of the lens has become more convex.

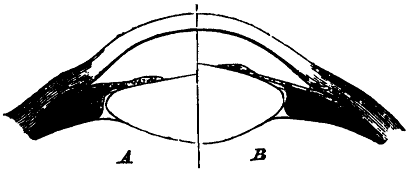

FIG. 78.
Illustrates the change in the form of the lens when adjusted—*A* to distant, *B* to near objects.

The change of form of the lens is, in fact, that represented in Fig. 78.

These may be regarded as the *facts of adjustment* with which all explanations of that process must accord. They at once exclude the hypothesis (1) that adjustment is the result of the compression of the ball of the eye by its muscles, which would cause a change in the form of the cornea; (2) that adjustment results from a shifting of the lens bodily, for its hinder face does not move; (3) that it results from the pressure of the iris upon the front face of the lens, for under these circumstances the hinder face of the lens would not remain stationary. This last hypothesis is further negatived by the fact that adjustment takes place equally well when the iris is absent.

One other explanation remains, which is, not only exceedingly probable from the anatomical relations of the parts, but is also supported by direct experimental evidence. The lens, which is very elastic, is kept habitually in a state of tension by the pressure exerted by its suspensory ligament, and consequently has a flatter form than it would take if left to itself. If the ciliary muscle contracts, it must, as has been seen, relax that ligament, and thereby diminish its pressure upon the lens. The lens, consequently, will become more convex; it will, however, return to its former shape when the ciliary muscle ceases to contract, and allows the choroid to return to its ordinary place.

Hence probably the sense of effort we feel when we adjust for near distances arises from the contraction of the ciliary muscle.

22. Adjustment can take place only within a certain range; this, however, admits of great individual variations.

People possessing ordinary or as it is called "normal" sight can adjust their eyes so as to see distinctly objects as near to the eye as five or six inches; but the image of an object brought nearer than this becomes blurred and indistinct, because the "near limit" of adjustment is then passed. They can also adjust their eyes for objects at a very great distance, the indistinctness of the images of objects very far off being due not to want of proper focussing, but to the details being lost through the minuteness of the image.

Some people, however, are born with, or at least come to possess eyes, in which the "near limit" of adjustment is much closer. Such persons can see distinctly objects as near to the cornea as even one or two inches; but they cannot adjust their eyes to objects at any great distance off. Thus many of these "near-sighted" people, as they are called, cannot see distinctly the features of a person only a few feet off. Though their ciliary muscle remains quite relaxed so that the suspensory ligament keeps the lens as flat as possible, the arrangements of the eye are such that the image of an object only a few feet off is brought to a focus before the retina, somewhere in the vitreous humour. By wearing concave glasses these

near-sighted people are able to bring the image of distant objects on to the retina and thus to see them distinctly.

The cause of near-sightedness is not always the same, but in the majority of cases it appears to be due to the bulb of the eye being unusually long from back to front. If, in the water camera described above, when the lens and object were so adjusted that the image of the object was distinctly focussed on the screen, the box were made longer, so that the screen was moved backwards, the distinctness of the image on it would be lost.

Some people are born really "long-sighted," inasmuch as they can see distinctly only such objects as are quite distant; and indeed have to contract their ciliary muscles, and so make their lens more convex even to see these. Near objects they cannot see distinctly at all unless they use convex glasses. In such persons the bulb of the eye is generally too short.

A kind of long-sightedness also comes on in old people; but this is different from the above, and is simply due, in the majority of cases at all events, to a loss of power of adjustment. The refractive power of the eye remains the same, but the ciliary muscle fails to work; and hence adjustment for near objects becomes impossible, though distant objects are seen as before. For near objects such persons have to use convex glasses. They should perhaps be called "old-sighted" rather than "long-sighted."

In the water camera the image brought to a focus on the screen at the back is *inverted;* the image of a tree for instance is seen with the roots upwards and the leaves and branches hanging downwards. The right of the image also corresponds with the left of the object and *vice versâ.* Exactly the same thing takes place in the eye with the image focussed on the retina. It too is inverted. (See Lesson X. § 11.)

23. The *muscles* which move the eyeball are altogether six in number—four straight muscles, or *recti*, and two oblique muscles, the *obliqui* (Fig. 79). The straight muscles are attached to the back of the bony orbit, round the edges of the hole through which the optic nerve passes, and run straight forward to their insertions into the sclerotic—one, the *superior rectus*, in the middle line above; one, the *inferior*, opposite it below; and one

half-way on each side, the *external* and *internal recti*. The eyeball is completely imbedded in fat behind and laterally; and these muscles turn it as on a cushion; the superior rectus inclining the axis of the eye upwards, the inferior downwards, the external outwards, the internal inwards.

The two oblique muscles, upper and lower, are both attached on the outer side of the ball, and rather behind its centre; and they both pull in a direction from the point of attachment towards the inner side of the orbit—the lower, because it arises here; the upper, because,

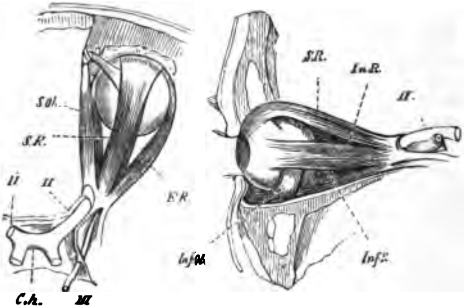

FIG. 79.

A, the muscles of the right eyeball viewed from above, and B of the left eyeball viewed from the outer side; *S.R.* the superior rectus; *Inf.R.* the inferior rectus; *E.R.*, *In.R.* the external rectus; *S.Ob.* the superior oblique; *Inf.Ob.* the inferior oblique; *Ch.* the chiasma of the optic nerves (*II.*); *III*, the third nerve which supplies all the muscles except the superior oblique and the external rectus.

though it arises along with the recti from the back of the orbit, yet, after passing forwards and becoming tendinous at the upper and inner corner of the orbit, it traverses a pulley-like loop of ligament, and then turns downwards and outwards to its insertion. The action of the oblique muscles is somewhat complicated, but their general tendency is to roll the eyeball on its axis, and pull it a little forward and inward.

24. The *eyelids* are folds of skin containing thin plates of cartilage, and fringed at the edges with hairs, the *eye-*

lashes, and with a series of small glands called *Meibomian*. Circularly disposed fibres of striped muscle lie beneath the integuments of the eyelids, and constitute the *orbicularis* muscle which shuts them. The upper eyelid is raised by a special muscle, the *levator* of the upper lid which arises at the back of the orbit and runs forwards to end in the lid.

The lower lid has no special depressor.

25. At the edge of the eyelids the integument becomes continuous with a delicate, vascular and highly nervous mucous membrane, the *conjunctiva*, which lines the interior of the lids and the front of the eyeball, its epithelial

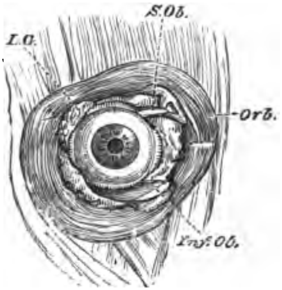

FIG. 80.

The front view of the right eye dissected to show, *Orb.*, the orbicular muscle of the eyelids; the pulley and insertion of the superior oblique, *S.Ob.*, and the inferior oblique, *Inf.Ob.*; *L.G.*, the lachrymal gland.

layer being even continued over the cornea. The numerous small ducts of a gland which is lodged in the orbit, on the outer side of the ball (Fig. 80, *L.G.*), the *lachrymal gland*, constantly pour its watery secretion into the interspace between the conjunctiva lining the upper eyelid and that covering the ball. On the inner side of the eye is a reddish fold, the *caruncula lachrymalis*, a sort of rudiment of that third eyelid which is to be found in many animals. Above and below, close to the caruncular, the edge of each eyelid presents a minute aperture (the *punctum lachrymale*), the opening of a small canal. The

canals from above and below converge and open into the *lachrymal sac;* the upper blind end of a duct (*L.D.*, Fig. 81) which passes down from the orbit to the nose, opening below the inferior turbinal bone (Fig. 40, *h*). It is through this system of canals that the conjunctival mucous membrane is continuous with that of the nose; and it is

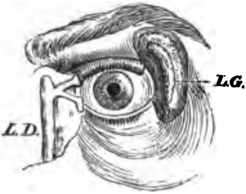

FIG. 81.
A front view of the left eye, with the eyelids partially dissected to show lachrymal gland, *L.G.*, and lachrymal duct, *L.D.*

by them that the secretion of the lachrymal gland is ordinarily carried away as fast as it forms.

But, under certain circumstances, as when the conjunctiva is irritated by pungent vapours, or when painful emotions arise in the mind, the secretion of the lachrymal gland exceeds the drainage power of the lachrymal duct, and the fluid, accumulating between the lids, at length overflows in the form of tears.

LESSON X.

THE COALESCENCE OF SENSATIONS WITH ONE ANOTHER AND WITH OTHER STATES OF CONSCIOUSNESS.

1. IN explaining the functions of the sensory organs, I have hitherto confined myself to describing the means by which the physical agent of a sensation is enabled to irritate a given sensory nerve; and to giving some account of the simple sensations which are thus evolved.

Simple sensations of this kind are such as might be produced by the irritation of a single nerve-fibre, or of several nerve-fibres by the same agent. Such are the sensations of contact of warmth, of sweetness, of an odour, of a musical note, of whiteness, or redness.

But very few of our sensations are thus simple. Most of even those which we are in the habit of regarding as simple, are really compounds of different simultaneous sensations, or of present sensations with past sensations, or with those feelings of relation which form the basis of judgments. For example, in the preceding cases it is very difficult to separate the sensation of contact from the judgment that something is touching us; of sweetness, from the idea of something in the mouth; of sound or light, from the judgment that something outside us is shining, or sounding.

2. The sensations of smell are those which are least complicated by accessories of this sort. Thus, particles of musk diffuse themselves with great rapidity through the nasal passages, and give rise to the sensation of

a powerful odour. But beyond a broad notion that the odour is in the nose, this sensation is unaccompanied by any ideas of locality and direction. Still less does it give rise to any conception of form, or size, or force, or of succession, or contemporaneity. If a man had no other sense than that of smell, and musk were the only odorous body, he could have no sense of *outness*—no power of distinguishing between the external world and himself.

3. Contrast this with what may seem to be the equally simple sensation obtained by drawing the finger along the table, the eyes being shut. This act gives one the sensation of a flat, hard surface outside oneself, which sensation appears to be just as simple as the odour of musk, but is really a complex state of feeling compounded of—

(*a*) Pure sensations of contact.

(*b*) Pure muscular sensations of two kinds,—the one arising from the resistance of the table, the other from the actions of those muscles which draw the finger along.

(*c*) Ideas of the order in which these pure sensations succeed one another.

(*d*) Comparisons of these sensations and their order, with the recollection of like sensations similarly arranged, which have been obtained on previous occasions.

(*e*) Recollections of the impressions of extension, flatness, &c. made on the organ of vision when these previous tactile and muscular sensations were obtained.

Thus, in this case, the only pure sensations are those of contact and muscular action. The greater part of what we call the sensation is a complex mass of present and recollected sensations and judgments.

4. Should any doubt remain that we do thus mix up our sensations with our judgments into one indistinguishable whole, shut the eyes as before, and, instead of touching the table with the finger, take a round lead pencil between the fingers, and draw that along the table. The "sensation" of a flat hard surface will be just as clear as before; and yet all that we touch is the round surface of the pencil, and the only pure sensations we owe to the table are those afforded by the muscular sense. In fact, in this case, our "sensation" of a flat hard

surface is entirely a judgment based upon what the muscular sense tells us is going on in certain muscles.

A still more striking case of the tenacity with which we adhere to complex judgments, which we conceive to be pure sensations, and are unable to analyse otherwise than by a process of abstract reasoning, is afforded by our sense of roundness.

Any one taking a marble between two fingers will say that he feels it to be a single round body; and he will probably be as much at a loss to answer the question how he knows that it is round, as he would be if he were asked how he knows that a scent is a scent.

Nevertheless, this notion of the roundness of the marble is really a very complex judgment, and that it is so may be shown by a simple experiment. If the index and middle fingers be crossed, and the marble placed between them, so as to be in contact with both, it is utterly impossible to avoid the belief that there are two marbles instead of one. Even looking at the marble, and seeing that there is only one, does not weaken the apparent proof derived from touch that there are two.[1]

The fact is, that our notions of singleness and roundness are, really, highly complex judgments based upon a few simple sensations; and when the ordinary conditions of those judgments are reversed, the judgment is also reversed.

With the index and the middle fingers in their ordinary position, it is of course impossible that the outer sides of each should touch opposite surfaces of one spheroidal body. If, in the natural and usual position of the fingers, their outer surfaces simultaneously give us the impression of a spheroid (which itself is a complex judgment), it is in the nature of things that there must be two spheroids. But, when the fingers are crossed over the marble, the outer side of each finger is really in contact with a spheroid; and the mind, taking no cognizance of the crossing, judges in accordance with its universal

[1] A ludicrous form of this experiment is to apply the crossed fingers to the end of the nose, when it at once appears double; and in spite of the absurdity of the conviction, the mind cannot expel it, so long as the sensations last.

experience, that two spheroids, and not one, give rise to the sensations which are perceived.

5. Phenomena of this kind are not uncommonly called *delusions of the senses;* but there is no such thing as a fictitious, or delusive, sensation. A sensation must exist to be a sensation, and, if it exists, it is real and not delusive. But the judgments we form respecting the causes and conditions of the sensations of which we are aware, are very often erroneous and delusive enough; and such judgments may be brought about in the domain of every sense, either by artificial combinations of sensations, or by the influence of unusual conditions of the body itself. The latter give rise to what are called *subjective sensations.*

Mankind would be subject to fewer delusions than they are, if they constantly bore in mind their liability to false judgments due to unusual combinations, either artificial or natural, of true sensations. Men say, "I felt," "I heard," "I saw" such and such a thing, when, in ninety-nine cases out of a hundred, what they really mean is, that they judge that certain sensations of touch, hearing, or sight, of which they were conscious, were caused by such and such things.

6. Among *subjective sensations* within the domain of touch, are the feelings of creeping and prickling of the skin, which may sometimes be due to certain states of the circulation, but probably more frequently to processes going on in the central nervous system. The subjective evil smells and bad tastes which accompany some diseases are, in a similar way, very probably due to disturbances in the brain in the central end-organs of the nerves of smell and taste.

Many persons are liable to what may be called *auditory spectra*—music of various degrees of complexity sounding in their ears, without any external cause, while they are wide awake. I know not if other persons are similarly troubled, but in reading books written by persons with whom I am acquainted, I am sometimes tormented by hearing the words pronounced in the exact way in which these persons would utter them, any trick or peculiarity of voice, or gesture, being, also, very accurately reproduced. And I suppose that every one must have

been startled, at times, by the extreme distinctness with which his thoughts have embodied themselves in apparent voices.

The most wonderful exemplifications of subjective sensation, however, are afforded by the organ of sight.

Any one who has witnessed the sufferings of a man labouring under *delirium tremens* (a disease produced by excessive drinking), from the marvellous distinctness of his visions, which sometimes take the forms of devils, sometimes of creeping animals, but almost always of something fearful or loathsome, will not doubt the intensity of subjective sensations in the domain of vision.

7. But in order that illusive visions of great distinctness should appear, it is not necessary for the nervous system to be thus obviously deranged. People in the full possession of their faculties, and of high intelligence, may be subject to such appearances, for which no distinct cause can be assigned. An excellent illustration of this is the famous case of Mrs. A. given by Sir David Brewster, in his *Natural Magic*. This lady was subject to unusually vivid auditory and ocular spectra. Thus on one occasion she saw her husband standing before her and looking fixedly at her with a serious expression, though at the time he was at another place. On another occasion she heard him repeatedly call her, though at the time he was not anywhere near. On another occasion she saw a cat in the room lying on the rug; and so vivid was the illusion that she had great difficulty in satisfying herself that really there was no cat there. The whole account is well worthy of perusal.

It is obvious that nothing but the singular courage and clear intellect of Mrs. A. prevented her from becoming a mine of ghost stories of the most excellently authenticated kind. And the particular value of her history lies in its showing, that the clearest testimony of the most unimpeachable witness may be quite inconclusive as to the objective reality of something which the witness has seen.

Mrs. A. undoubtedly saw what she said she saw. The evidence of her eyes as to the existence of the apparitions, and of her ears to those of the voices, was, in itself, as perfectly trustworthy as their evidence would have been

had the objects really existed. For there can be no doubt that exactly those parts of her retina which would have been affected by the image of a cat, and those parts of her auditory organ which would have been set vibrating by her husband's voice, or the portions of the sensorium with which those organs of sense are connected, were thrown into a corresponding state of activity by some internal cause.

What the senses testify is neither more nor less than the fact of their own affection. As to the cause of that affection they really say nothing, but leave the mind to form its own judgment on the matter. A hasty or superstitious person in Mrs. A.'s place would have formed a wrong judgment, and would have stood by it on the plea that "she must believe her senses."

8. The delusions of the judgment, produced not by abnormal conditions of the body, but by unusual or artificial combinations of sensations, or by suggestions of ideas, are exceedingly numerous, and, occasionally are not a little remarkable.

Some of those which arise out of the sensation of touch have already been noted. I do not know of any produced through smell or taste, but hearing is a fertile source of such errors.

What is called *ventriloquism* (speaking from the belly), and is not uncommonly ascribed to a mysterious power of producing voice somewhere else than in the larynx, depends entirely upon the accuracy with which the performer can simulate sounds of a particular character, and upon the skill with which he can suggest a belief in the existence of the causes of these sounds. Thus, if the ventriloquist desire to create the belief that a voice issues from the bowels of the earth, he imitates with great accuracy the tones of such a half-stifled voice, and suggests the existence of some one uttering it by directing his answers and gestures towards the ground. These gestures and tones are such as would be produced by a given cause; and no other cause being apparent, the mind of the bystander insensibly judges the suggested cause to exist.

9. The delusions of the judgment through the sense of sight—*optical delusions*, as they are called—are more

numerous than any others, because such a great number of what we think to be simple visual sensations are really very complex aggregates of visual sensations, tactile sensations, judgments, and recollections of former sensations and judgments.

It will be instructive to analyse some of these judgments into their principles, and to explain the delusions by the application of these principles.

10. *When we look at an external object, the image of the object falls on the retina at the end of the visual axis*, i.e., *a line joining the object and the retina and traversing a particular region of the centre of the eye. Conversely, when a part of the retina is excited, by whatever means, the sensation is referred by the mind to some cause outside the body in the direction of the visual axis.*

When we look at an external object which is felt by the touch to be in a given place, the image of the object falls upon a certain part of the retina. Conversely, when a part of the retina is excited, by whatever means, the sensation is referred by the mind to some cause outside the body occupying such a position that its image would fall on that part.

It is for this reason that when a phosphene is created by pressure, say on the outer and lower side of the eyeball, the luminous image appears to lie above, and to the inner side of, the eye. Any external object which could produce the sense of light in the part of the retina pressed upon must, owing to the inversion of the retinal images (see Lesson IX. § 23), in fact occupy this position; and hence the mind refers the light seen to an object in that position.

11. The same kind of explanation is applicable to the apparent paradox that, while all the pictures of external objects are certainly inverted on the retina by the refracting media of the eye, we nevertheless see them upright. It is difficult to understand this, until one reflects that the retina has, in itself, no means of indicating to the mind which of its parts lies at the top, and which at the bottom; and that the mind learns to call an impression on the retina high or low, right or left, simply on account of the association of such an impression with certain coincident tactile impressions. In other words, when one part of the

retina is affected, the object causing the affection is found to be near the right hand; when another, the left; when another, the hand has to be raised to reach the object; when yet another, it has to be depressed to reach it. And thus the several impressions on the retina are called right, left, upper, lower, quite irrespectively of their real positions, of which the mind has, and can have, no cognizance.

12. *When an external body is ascertained by touch to be simple, it forms but one image on the retina of a single eye; and when two or more images fall on the retina of a single eye, they ordinarily proceed from a corresponding number of bodies which are distinct to the touch.*

Conversely, the sensation of two or more images is judged by the mind to proceed from two or more objects.

If two pin-holes be made in a piece of cardboard at a distance less than the diameter of the pupil, and a small object like the head of a pin be held pretty close to the eye, and viewed through these holes, two images of the head of the pin will be seen. The reason of this is, that the rays of light from the head of the pin are split by the card into two minute pencils, which pass into the eye on either side of its centre, and, on account of the nearness of the pin to the eye, meet the retina before they can be united again and brought to one focus. Hence they fall on different parts of the retina, and each pencil of rays being very small, makes a tolerably distinct image of its own of the pin's head on the retina. Each of these images is now referred outward (§ 10) and two pins are apparently seen instead of one. A like explanation applies to *multiplying glasses* and *doubly refracting* crystals, both of which, in their own ways, split the pencils of light proceeding from a single object into two or more separate bundles. These give rise to as many images, each of which is referred by the mind to a distinct external object.

13. *Certain visual phenomena ordinarily accompany those products of tactile sensation to which we give the name of size, distance, and form. Thus, other things being alike, the space of the retina covered by the image of a large object is larger than that covered by a small object; while that covered by an object when near is larger*

than that covered by the same object when distant; and, other conditions being alike, a near object is more brilliant than a distant one. Furthermore, the shadows of objects differ according to the forms of their surfaces, as determined by touch.

Conversely, if these visual sensations can be produced, they inevitably suggest a belief in the existence of objects competent to produce the corresponding tactile sensations.

What is called *perspective*, whether *solid* or *aërial* in drawing, or painting, depends on the application of these principles. It is a kind of visual ventriloquism—the painter putting upon his canvas all the conditions requisite for the production of images on the retina, having the size, relative form, and intensity of colour of those which would actually be produced by the objects themselves in nature. And the success of his picture, as an imitation, depends upon the closeness of the resemblance between the images it produces on the retina, and those which would be produced by the objects represented.

14. To most persons the image of a pin, at three or four inches from the eye, appears blurred and indistinct —the eye not being capable of adjustment to so short a focus. If a small hole be made in a piece of card, the circumferential rays which cause the blur are cut off, and the image becomes distinct. But at the same time it is magnified, or looks bigger, because the image of the pin, in spite of the loss of the circumferential rays, occupies a much larger extent of the retina when close than when distant. All convex glasses produce the same effect— while concave lenses diminish the apparent size of an object, because they diminish the size of its image on the retina.

15. The moon, or the sun, when near the horizon appears very much larger than when it is high in the sky. When in the latter position, in fact, we have nothing to compare it with, and the small extent of the retina which its image occupies suggests small absolute size. But as it sets, we see it passing behind great trees and buildings which we know to be very large and very distant, and yet it occupies a larger space on the retina than they do. Hence the vague suggestion of its larger size.

16. If a convex surface be lighted from one side, the side towards the light is bright—that turned from the light, dark, or in shadow; while a concavity is shaded on the side towards the light, bright on the opposite side.

If a new half-crown, or a medal with a well-raised head upon its face, be lighted sideways by a candle, we at once know the head to be raised (or a *cameo*) by the disposition of the light and shade; and if an *intaglio*, or medal on which the head is hollowed out, be lighted in the same way, its nature is as readily judged by the eye.

But now, if either of the objects thus lighted be viewed with a convex lens, which inverts its position, the light and dark sides will be reversed. With the reversal the judgment of the mind will change, so that the cameo will be regarded as an intaglio, and the intaglio as a cameo; for the light still comes from where it did, but the cameo appears to have the shadows of an intaglio, and *vice versâ*. So completely, however, is this interpretation of the facts a matter of judgment, that if a pin be stuck beside the medal so as to throw a shadow, the pin and its shadow, being reversed by the lens, will suggest that the direction of the light is also reversed, and the medals will seem to be what they really are.

17. *Whenever an external object is watched rapidly changing its form, a continuous series of different pictures of the object is impressed upon the same spot of the retina.*

Conversely, if a continuous series of different pictures of one object is impressed upon one part of the retina, the mind judges that they are due to a single external object, undergoing changes of form.

This is the principle of the curious toy called the *thaumatrope*, or "zootrope," or "wheel of life," by the help of which, on looking through a hole, one sees images of jugglers throwing up and catching balls, or boys playing at leapfrog over one another's backs. This is managed by painting at intervals, on a disk of card, figures and jugglers in the attitudes of throwing, waiting to catch, and catching; or boys "giving a back," leaping, and coming into position after leaping. The disk is then made to rotate before an opening, so that each image shall be presented for an instant, and follow its predecessor before the

impression of the latter has died away. The result is that the succession of different pictures irresistibly suggests one or more objects undergoing successive changes—the juggler seems to throw the balls, and the boys appear to jump over one another's backs.

18. *When an external object is ascertained by touch to be single, the centres of its retinal images in the two eyes fall upon the centres of the yellow spots of the two eyes, when both eyes are directed towards it; but if there be two external objects, the centres of both their images cannot fall, at the same time, upon the centres of the yellow spots.*

Conversely, when the centres of two images, formed simultaneously in the two eyes, fall upon the centres of the yellow spots, the mind judges the images to be caused by a single external object; but if not, by two.

This seems to be the only admissible explanation of the facts, that an object which appears single to the touch and when viewed with one eye, also appears single when it is viewed with both eyes, though two images of it are necessarily formed; and on the other hand, that when the centres of the two images of one object do not fall on the centres of the yellow spots, both images are seen separately, and we have double vision. In squinting, the axes of the two eyes do not converge equally towards the object viewed. In consequence of this, when the centre of the image formed by one eye falls on the centre of the yellow spot, the corresponding part of that formed by the other eye does not, and double vision is the result.

For simplicity's sake we have supposed the images to fall on the centre of the yellow spot. But though vision is distinct only in the yellow spot, it is not absolutely limited to it; and it is quite possible for an object to be seen as a single object with two eyes, though its images fall on the two retinas outside the yellow spots. All that is necessary is that the two spots of the retinas on which the images fall should be similarly disposed towards the centres of their respective yellow spots. Any two points of the two retinas thus similarly disposed towards their respective yellow spots (or more exactly to the points in which the visual axes end), are spoken of as *corresponding points;* and any two images covering two corresponding areas are conceived of as coming from a single object. It is obvious

that the inner (or nasal) side of one retina *corresponds* to the outer (or cheek) side of the other.

19. *In single vision with two eyes, the axes of the two eyes, of the movements of which the muscular sense gives an indication, cut one another at a greater angle when the object approaches, at a less angle when it goes further off.*

Conversely, if without changing the position of an object, the axes of the two eyes which view it can be made to converge or diverge, the object will seem to approach or go further off.

In the instrument called the *pseudoscope*, mirrors or prisms are disposed in such a manner that the angle at which rays of light from an object enter the two eyes, can be altered without any change in the object itself; and consequently the axes of these eyes are made to converge or diverge. In the former case the object seems to approach; in the latter, to recede.

20. *When a body of moderate size, ascertained by touch to be solid, is viewed with both eyes, the images of it, formed by the two eyes, are necessarily different (one showing more of its right side, the other of its left side). Nevertheless, they coalesce into a common image, which gives the impression of solidity.*

Conversely, if the two images of the right and left aspects of a solid body be made to fall upon the retinas of the two eyes in such a way as to coalesce into a common image, they are judged by the mind to proceed from the single solid body which alone, under ordinary circumstances, is competent to produce them.

The *stereoscope* is constructed upon this principle. Whatever its form, it is so contrived as to throw the images of two pictures of a solid body, such as would be obtained by the right and left eye of a spectator, on to such parts of the retinas of the person who uses the stereoscope as would receive these images, if they really proceeded from one solid body. The mind immediately judges them to arise from a single external solid body, and sees such a solid body in place of the two pictures.

The operation of the mind upon the sensations presented to it by the two eyes is exactly comparable to that which takes place when, on holding a marble between the finger and thumb, we at once declare it to be a single sphere

(§ 4). That which is absolutely presented to the mind by the sense of touch in this case is by no means the sensation of one spheroidal body, but two distinct sensations of two convex surfaces. That these two distinct convexities belong to one sphere, is an act of judgment, or process of unconscious reasoning, based upon many particulars of past and present experience, of which we have, at the moment, no distinct consciousness.

LESSON XI.

THE NERVOUS SYSTEM AND INNERVATION.

1. THE sensory organs are, as we have seen, the channels through which particular physical agents are enabled to excite the sensory nerves with which these organs are connected ; and the activity of these nerves is evidenced by that of the central organ of the nervous system, which activity becomes manifest as a state of consciousness—the sensation.

We have also seen that the muscles are instruments by which a motor nerve, excited by the central organ with which it is connected, is able to produce motion.

The sensory nerves, the motor nerves, and the central organ, constitute the greater part of the *nervous system*, which, with its function of *innervation*, we must now study somewhat more closely, and as a whole.

2. The nervous apparatus consists of two sets of nerves and nerve-centres, which are intimately connected together and yet may be conveniently studied apart. These are the *cerebro-spinal* system and the *sympathetic* system. The former consists of the *cerebro-spinal axis* (composed of the *brain* and *spinal cord*) and the cranial and *spinal nerves*, which are connected with this axis. The latter comprises the chain of *sympathetic ganglia*, the nerves which they give off, and the various cords by which they are connected with one another and with the cerebro-spinal nerves.

Nerves are made up entirely of nerve-fibres, the structure of which is somewhat different in the cerebro-spinal

and in the sympathetic systems. (See Lesson XII.) Nerve centres, on the other hand, are composed of *nerve-cells* mingled with nerve-fibres (Lesson XII.). Such nerve-cells are found in various parts of the brain and spinal cord, in the sympathetic ganglia, and also in the ganglia belonging to spinal nerves as well as in certain sensory organs, such as the retina and the internal ear.

3. The *cerebro-spinal axis* lies in the cavity of the skull and spinal column, the bony walls of which cavity are lined by a very tough fibrous membrane, serving as the periosteum of the component bones of this region, and called the *dura mater*. The brain and spinal cord themselves are closely invested by a very vascular fibrous tissue, called *pia mater*. The numerous blood vessels supplying these organs run for some distance in the pia mater, and where they pass into the substance of the brain or cord, the fibrous tissue of the pia mater accompanies them to a greater or less depth.

Between the *pia mater*, and the *dura mater*, lies another delicate membrane, called the *arachnoid* membrane. These three membranes are connected with each other at various points, and the arachnoid, which is not only very delicate, but also less regular than the other two, divides the space between the dura and pia mater into two spaces, each containing fluid, and each more or less lined by a delicate epithelium. The space between the dura mater and the arachnoid, often called the *sub-dural space*, is nowhere very large; but the space between the arachnoid and the pia mater, often called the *sub-arachnoid space*, though small and insignificant in the region of the brain, becomes large in the region of the spinal cord, and here contains a considerable quantity of fluid, called *arachnoid* or *subarachnoid fluid*.

4. The *spinal cord* (Fig. 82) is a column of greyish-white soft substance, extending from the top of the spinal canal, where it is continuous with the brain, to about the second lumbar vertebra, where it tapers off into a filament. A deep, somewhat broad, fissure, the *anterior fissure* (Fig. 83, *1*), divides it in the middle line in front, nearly down to its centre: and a similar deeper but narrower cleft, the *posterior fissure* (Fig. 83, *2*), also extends nearly to its centre in the middle line behind. The pia mater

extends more or less into each of these fissures, and supports the vessels which supply the cord with blood. In consequence of the presence of these fissures, only a narrow bridge of the substance of the cord connects its two halves, and this bridge is traversed throughout its entire length by a minute canal, the *central canal* of the cord (Fig. 83, *3*).

Each half of the cord is divided longitudinally into three parts, the anterior, lateral, and posterior columns (Fig. 83, *6*, *7*, *8*), by the lines of attachment of two parallel series of delicate bundles of nervous filaments, the roots of the spinal nerves. The roots of the nerves which arise

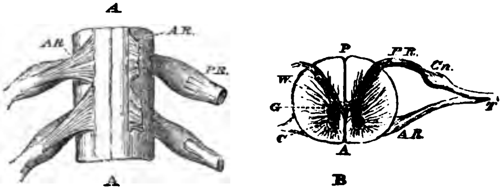

FIG. 82.—THE SPINAL CORD.

A. A front view of a portion of the cord. On the right side, the anterior roots, *A.R.*, are entire; on the left side they are cut, to show the posterior roots, *P.R.*

B. A transverse section of the cord. *A*, the anterior fissure; *P*, the posterior fissure; *G*, the central canal; *C*, the grey matter; *W*, the white matter; *A.R.*, the anterior root, *P.R.*, the posterior root, *Gn.*, the ganglion, and *T*, the trunk, of a spinal nerve.

along that line which is nearer the posterior surface of the cord are called *posterior roots;* those which arise along the other line are the *anterior roots.* A certain number of anterior and posterior roots, on the same level on each side of the cord, converge and form anterior and posterior bundles, and then the two bundles, anterior and posterior, coalesce into the trunk of a spinal nerve; but before doing so, the posterior bundle presents an enlargement—*the ganglion of the posterior root.*

The trunks of the spinal nerves pass out of the spinal canal by apertures between the vertebræ, called the *intervertebral foramina,* and then divide and subdivide, their

ultimate ramifications going for the most part to the muscles and to the skin.

There are thirty-one pair, of these spinal nerves, and,

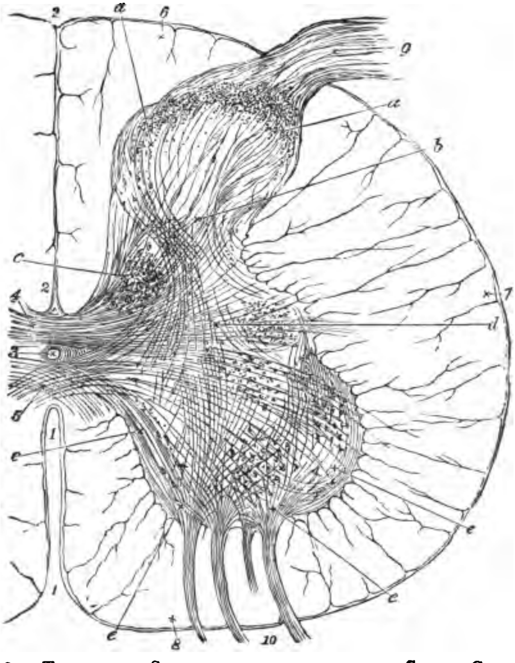

FIG. 83.—TRANSVERSE SECTION OF ONE-HALF OF THE SPINAL CORD (IN THE LUMBAR REGION), MAGNIFIED.

1, anterior fissure; 2, posterior fissure; 3, central canal; 4 and 5, bridges connecting the two halves (posterior and anterior commissures); 6, posterior column; 7, lateral column; 8, anterior column; 9, posterior root; 10, anterior root of nerve.

a a, posterior horn of grey matter; *e e e*, anterior horn of grey matter. Through the several columns 6, 7, and 8, each composed of white matter, are seen the prolongations of the pia mater, which carry blood-vessels into the cord from the outside. The pia mater itself is seen over the whole of the cord.

consequently, twice as many sets of roots of spinal nerves given off, in two lateral series, from each half of the cord.

5. A transverse section of the cord (Fig. 82, B, and Fig. 83) shows that each half contains two substances—a white substance on the outside, and a greyish-red substance in the interior. And this *grey matter*, as it is called, is so disposed that, in a transverse section, it looks, in each half, something like a crescent, with one end bigger than the other, and with the concave side turned outwards. The two ends of the crescents are called its *horns* or *cornua* (Fig. 83, *e e*), the one directed forwards being the *anterior cornu;* the one turned backwards the *posterior cornu* (Fig. 83, *a a*). The convex sides of the cornua of the grey matter approach one another, and are joined by the bridge which contains the central canal.

There is a fundamental difference in structure between the grey and the white matter. The white matter consists entirely of nerve-fibres supported in a delicate framework of connective tissue, and accompanied by blood-vessels. Most of these fibres run lengthways in the cord, and consequently, in a transverse section, the white matter is really composed of a multitude of the cut ends of these fibres.

The grey matter, on the other hand, contains in addition a number of nerve-cells, some of them of considerable size. These cells are wholly absent in the white matter.

Many of the nerve-fibres of which the anterior roots are composed may be traced into the anterior cornu, and, indeed, into the nerve-cells lying in the cornu, while those of the posterior roots, for the most part, enter or pass through the posterior cornu.

6. The physiological properties of the organs now described are very remarkable.

If the *trunk* of a spinal nerve be irritated in any way, as by pinching, cutting, galvanizing, or applying a hot body, two things happen: in the first place, all the muscles to which filaments of this nerve are distributed, contract; in the second, pain is felt, and the pain is referred to that part of the skin to which fibres of the nerve are distributed. In other words, the effect of irritating the trunk of a nerve is the same as that of irritating its component fibres at their terminations.

The effects just described will follow upon irritation of any part of the *branches* of the nerve : except that when a branch is irritated, the only muscles directly affected, and the only region of the skin to which pain is referred, will be those to which that branch sends nerve-fibres. And these effects will follow upon irritation of any part of a nerve from its smallest branches up to the point of its trunk, at which the anterior and posterior bundles of root fibres unite.

7. If the anterior bundle of root fibres be irritated in the same way, only half the previous effects are brought about. That is to say, all the muscles to which the nerve is distributed contract, but no pain is felt.

So again if the posterior, ganglionated bundle be irritated, only half the effects of irritating the whole trunk is produced. But it is the other half; that is to say, none of the muscles to which the nerve is distributed contract, but pain is referred to the whole area of skin to which the fibres of the nerve are distributed.

8. It is clear enough, from these experiments, that all the power of causing muscular contraction which a spinal nerve possesses, is lodged in the fibres which compose its anterior roots ; and all the power of giving rise to sensation, in those of its posterior roots. Hence the anterior roots are commonly called *motor*, and the posterior *sensory*.

The same truth may be illustrated in other ways. Thus, if, in a living animal, the anterior roots of a spinal nerve be cut, the animal loses all control over the muscles to which that nerve is distributed, though the sensibility of the region of the skin supplied by the nerve is perfect. If the posterior roots be cut, sensation is lost, and voluntary movement remains. But if both roots be cut, neither voluntary movement nor sensibility is any longer possessed by the part supplied by the nerve. The muscles are said to be paralysed; and the skin may be cut, or burnt, without any sensation being excited.

If, when both roots are cut, that end of the motor root which remains connected with the trunk of the nerve be irritated, the muscles contract; while, if the other end be so treated, no apparent effect results. On the other hand, if the end of the sensory root connected with the

trunk of the nerve be irritated, no apparent effect is produced, while, if the end connected with the cord be irritated, pain immediately follows.

When no apparent effect follows upon the irritation of any nerve, it is not probable that the molecules of the nerve remain unchanged. On the contrary, it would appear that the same change occurs in all cases; but a motor nerve is connected with nothing that can make that change apparent save a muscle, and a sensory nerve with nothing that can show an effect but the central nervous system.

9. It will be observed that in all the experiments mentioned there is evidence that, when a nerve is irritated, a something, probably, as we have seen (Lesson V., § 32), a change in the arrangement of its molecules, is propagated along the nerve-fibres. If a motor or a sensory nerve be irritated at any point, contraction in the muscle, or sensation or (some other corresponding event) in the central organ, immediately follows. But if the nerve be cut, or even tightly tied at any point between the part irritated and the muscle or central organ, the effect at once ceases, just as cutting a telegraph wire stops the transmission of the electric current or impulse. When a limb, as we say, "goes to sleep," it is frequently because the nerves supplying it have been subjected to pressure sufficient to destroy the nervous[1] continuity of the fibres. We lose voluntary control over, and sensation in, the limb, and these powers are only gradually restored as that nervous continuity returns.

Having arrived at this notion of an impulse travelling along a nerve, we readily pass to the conception of a sensory nerve as a nerve which, when active, brings an impulse to the central organ, or is *afferent;* and of a motor nerve, as a nerve which carries away an impulse from the organ, or is *efferent.* It is very convenient to use these terms to

[1] Their "nervous continuity"—because their physical continuity is not interrupted as a whole, but only that of the substance which acts as a conductor of the nervous influence; or, it may be that only the conducting power of a part of that substance is interfered with. Imagine a telegraph cable, made of delicate caoutchouc tubes, filled with mercury—a squeeze would interrupt the "electrical continuity" of the cable, without destroying its physical continuity. This analogy may not be exact, but it helps to make the nervous phenomena intelligible.

denote the two great classes of nerves; for, as we shall find (§ 12), there are afferent nerves which are not sensory in the sense of giving rise to a change of consciousness, or sensation, while there are efferent nerves which are not motor, in the sense of inducing muscular contraction. The nerves, for example, by which the electrical fishes give rise to discharges of electricity from peculiar organs to which those nerves are distributed, are efferent, inasmuch as they carry impulses to the electric organs, but are not motor, inasmuch as they do not give rise to movements. The pneumogastric when it stops the beat of the heart cannot be called a motor, and yet is then acting as an efferent nerve. It will, of course, be understood, as pointed out above, that the use of these words does not imply that when a nerve is irritated in the middle of its length, the impulses set up by that irritation travel only away from the central organ if the nerve be efferent, and towards it, if it be afferent. On the contrary, we have evidence that in both cases the impulses travel both ways. All that is meant is this, that the afferent nerve from the disposition of its two ends, in the skin, or other peripheral organs on the one hand, and in the central organ on the other, is of use only when impulses are travelling along it towards the central organ, and similarly the efferent nerve is of use only when impulses are travelling along it, away from the central organ.

10. There is no difference in structure, in chemical or in physical character, between afferent and efferent nerves. The impulse which travels along them requires a certain time for its propagation, and is vastly slower than many other movements—even slower than sound.

11. Up to this point our experiments have been confined to the nerves. We may now test the properties of the spinal cord in a similar way. If the cord be cut across (say in the middle of the back), the legs and all the parts supplied by nerves which come off below the section, will be insensible, and no effort of the will can make them move; while all the parts above the section will retain their ordinary powers.

When a man hurts his back by an accident, the cord is not unfrequently so damaged as to be virtually cut in two, and then paralysis and insensibility of the lower part of the body ensue.

If, when the cord is cut across in an animal, the cut end of the portion below the division, or away from the brain, be irritated, violent movements of all the muscles supplied by nerves given off from the lower part of the cord take place, but no sensation is felt by the brain. On the other hand, if that part of the cord, which is still connected with the brain, or better, if any afferent nerve connected with that part of the cord be irritated, sensations ensue, as is shown by the movements of the animal; but in these movements the muscles supplied by nerves coming from the spinal cord below the cut take no part; they remain perfectly quiet.

12. Thus, it may be said that, in relation to the brain the cord is a great mixed motor and sensory nerve. But it is also much more.

For if the trunk of a spinal nerve be cut through, so as to sever its connection with the cord, an irritation of the skin to which the sensory fibres of that nerve are distributed, produces neither motor nor sensory effect. But if the cord be cut through anywhere so as to sever its connection with the brain, irritation applied to the skin of the parts supplied with sensory nerves from the part of the cord below the section, though it gives rise to no sensation, may produce violent motion of the parts supplied with motor nerves from the same part of the cord.

Thus, in the case supposed above, of a man whose legs are paralysed and insensible from spinal injury, tickling the soles of the feet will cause the legs to kick out convulsively. And as a broad fact, it may be said that, so long as both roots of the spinal nerves remain connected with the cord, irritation of any afferent nerve is competent to give rise to excitement of some, or the whole, of the efferent nerves so connected.

If the cord be cut across a second time at any distance below the first section, the efferent nerves below the second cut will no longer be affected by irritation of the afferent nerves above it—but only of those below the second section. Or, in other words, in order that an afferent impulse may be converted into an efferent one by the spinal cord, the afferent nerve must be in uninterrupted material communication with the efferent nerve, by means of the substance of the spinal cord.

This peculiar power of the cord, by which it is competent to convert afferent into efferent impulses, is that which distinguishes it physiologically, as a central organ, from a nerve, and is called *reflex action.* It is a power possessed by the grey matter, and not by the white substance of the cord.

13. The number of the efferent nerves which may be excited by the reflex action of the cord, is not regulated alone by the number of the afferent nerves which are stimulated by the irritation which gives rise to the reflex action. Nor does a simple excitation of the afferent nerve by any means necessarily imply a corresponding simplicity in the arrangement and succession of the reflected motor impulses. Tickling the sole of the foot is a very simple excitation of the afferent fibres of its nerves; but in order to produce the muscular actions by which the legs are drawn up, a great multitude of efferent fibres must act in regulated combination. In fact, in a multitude of cases, a reflex action is to be regarded rather as the result of a dormant activity of the spinal cord awakened by the arrival of the afferent impulse, as a sort of orderly explosion fired off by the afferent impulse, than as a mere rebound of the afferent impulse into the first efferent channels open to it.

The various characters of these reflex actions may be very conveniently studied in the frog. If a frog be decapitated, or, better still, if the spinal cord be divided close to the head, and the brain be destroyed by passing a blunt wire into the cavity of the skull, the animal is thus deprived (by an operation which, being almost instantaneous, can give rise to very little pain) of all consciousness and volition, and yet the spinal cord is left intact. At first the animal is quite flaccid and apparently dead, no movement of any part of the body (except the beating of the heart) being visible. This condition, however, being the result merely of the so-called shock of the operation, very soon passes off, and then the following facts may be observed.

So long as the animal is untouched, so long as no stimulus is brought to bear upon it, no movement of any kind takes place: volition is wholly absent.

If, however, one of the toes be gently pinched, the leg is immediately drawn up close to the body.

If the skin between the thighs around the anus be pinched, the legs are suddenly drawn up and thrust out again violently.

If the flank be very gently stroked, there is simply a twitching movement of the muscles underneath; if it be more roughly touched, or pinched, these twitching movements become more general along the whole side of the creature, and extend to the other side, to the hind legs, and even to the front legs.

If the digits of the front limbs be touched, these will be drawn close under the body as in the act of clasping.

If a drop of vinegar or any acid be placed on the top of one thigh, rapid and active movements will take place in the leg. The foot will be seen distinctly trying to rub off the drop of acid from the thigh. And what is still more striking, if the leg be held tight and so prevented from moving, the other leg will begin to rub off the acid. Sometimes if the drop be too large or too strong, both legs begin at once, and then frequently the movements spread from the legs all over the body, and the whole animal is thrown into convulsions.

Now all these various movements, even the feeblest and simplest, require a certain combination of muscles, and some of them, such as the act of rubbing off the acid, are in the highest degree complex. In all of them, too, a certain purpose or end is evident, which is generally either to remove the body, or part of the body, from the stimulus, from the cause of irritation, or to thrust away the offending object from the body: in the more complex movements such a purpose is strikingly apparent.

It seems, in fact, that in the frog's spinal cord there are sets of nervous machinery destined to be used for a variety of movements, and that a stimulus passing along a sensory nerve to the cord sets one or the other of these pieces of machinery at work.

14. Thus one important function of the spinal cord is to serve as an independent nervous centre, capable of originating combined movements upon the reception of the impulse of an afferent nerve, or rather, perhaps, a group of such independent nervous centres.

But the spinal cord has another most important function, that of transmitting nervous impulses between the brain

and the various organs, such as the muscles and the skin, with which the spinal nerves are connected. When we move a foot, certain nervous impulses, starting in some part of the cerebral hemispheres, pass down along the whole length of the spinal cord as far as the roots of the spinal nerves going to the legs, and issuing along the fibres of the anterior bundles of these roots find their way to the muscles which move the foot. Similarly, when the sole of the foot is touched, afferent impulses travel in the reverse way upward along the spinal cord to the brain. And the question arises, in what manner do these efferent and afferent impulses travel along the spinal cord?

This question is one very difficult to answer, and indeed, a complete and exact statement is not, at present, possible. There is, however, a very considerable amount of evidence which goes to show that both afferent and efferent impulses, on their way between the brain and peripheral organs, pass chiefly along the longitudinal white fibres of the cord, especially along those placed in the lateral columns (§ 4 and Fig. 83). But the afferent impulses before they get into the lateral columns appear to have to make their way through a certain quantity of grey matter; similarly the efferent impulses when they leave the lateral columns appear to pass into the grey matter before they find their way into the anterior nerve roots; and we shall see in Lesson XII. that the fibres of the anterior roots are connected, in a special manner, with the nerve cells of the anterior cornua. There is also evidence to show that the grey matter itself may transmit both kinds of impulses, at least, for a certain distance.

From many experiments it would appear that both kinds of impulses have a tendency as they travel upwards or downwards in the spinal cord to cross over from one side of the cord to the other, and this seems to be especially the case with the afferent or sensory impulses. Thus a section of one lateral half of the cord in the dorsal region affects both the power of movement and the acuteness of the sensations in both legs.

But our knowledge of the way these impulses pass up and down the cord requires to be enlarged by further investigations before any very satisfactory statements can be made about them.

15. Such are the functions of the spinal cord, taken as a whole. The *spinal* nerves are, as we have said, chiefly distributed to the muscles and to the skin. But other nerves, such as those for instance belonging to the blood-vessels, the so-called *vaso-motor* nerves (Lesson II. § 23), though many of them run for long distances in the sympathetic system, may ultimately be traced to the spinal cord. Along the spinal column the spinal nerves give off branches which run into and join the sympathetic system. And the vaso-motor fibres which run along in the sympathetic nerves do really spring from the spinal cord, finding their way into the sympathetic system through these communicating or commissural branches. Besides which, some vaso-motor fibres run in spinal nerves along their whole course.

Experiments moreover go to show that the nervous influences which, through these vaso-motor nerves, regulate the blood-vessels, now forcibly constricting them, now allowing them to dilate, and now keeping them in a state of moderate or tonic constriction, proceed from the spinal cord.

The cord is, therefore, spoken of as containing *centres* for the vaso-motor nerves or, more shortly, *vaso-motor centres.*

For example, the muscular walls of the blood-vessels supplying the ear and the skin of the head generally, are made to contract, as has been already mentioned, by nervous fibres derived immediately from the sympathetic. These fibres, however, do not arise from the sympathetic ganglia, but simply pass through them on their way from the spinal cord, to the upper dorsal region of which they can all be traced. At least, this is the conclusion drawn from the facts, that irritation of this region of the cord produces the same effect as irritation of the vaso-motor nerves themselves, and that destruction of this part of the cord paralyses them.

It has, however, been further shown that the nervous influence does not originate here, but proceeds from higher up, from the medulla oblongata in fact, and simply passes down through this part of the spinal cord on its way to join the sympathetic nerves.

16. The brain (Fig. 84) is a complex organ, consisting

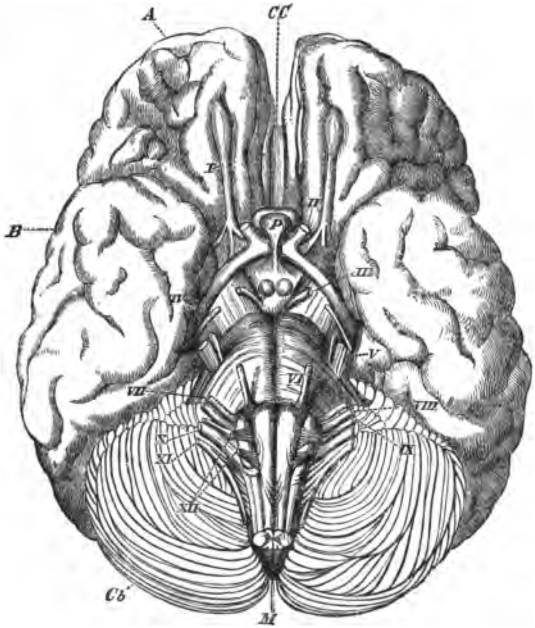

FIG. 84.—THE BASE OF THE BRAIN.

A. frontal lobe; *B*. temporal lobe of the cerebral hemispheres; *Cb*. cerebellum; *I*. the olfactory nerve; *II*. the optic nerve; *III*. *IV*. *VI*. the nerves of the muscles of the eye; *V*. the trigeminal nerve; *VII*. the portio dura; *VIII*. the auditory nerve; *IX*. the glossopharyngeal; *X*. the pneumogastric; *XI*. the spinal accessory; *XII*. the hypoglossal, or motor nerve of the tongue. The number *VI*. is placed upon the *pons Varolii*. The *crura cerebri* are the broad bundles of fibres which lie between the third and the fourth nerves on each side. The medulla oblongata (*M*) is seen to be really a continuation of the spinal cord; on the lower end are seen the two crescents of grey matter; the section, in fact, has been carried through the spinal cord, a little below the proper medulla oblongata. From the sides of the medulla oblongata are seen coming off the *X*., *XI*., and *XII*. nerves; and just where the medulla is covered, so to speak, by the transversely disposed *pons Varolii*, are seen coming off the *VII*. nerve, and more towards the middle line the *VI*. Out of the substance of the *pons* springs the *V*. nerve. In front of that is seen the well-defined anterior

of several parts, the hindermost of which, termed *medulla oblongata*, passes insensibly into, and in its lower part has the same structure as, the spinal cord.

Above, however, it widens out, and the central canal, spreading with it, becomes a broad cavity, which (leaving certain anatomical minutiæ aside) may be said to be widely open above. This cavity is termed the *fourth ventricle*. Overhanging the fourth ventricle is a great laminated mass, the *cerebellum* (*Cb.* Figs. 84, 85, 86). On each side, this organ sends down several layers of transverse fibres, which sweep across the brain and meet in the middle line of its base, forming a kind of bridge (called *pons Varolii*, Fig. 84) in front of the medulla oblongata. The longitudinal nerve-fibres of the medulla oblongata pass forwards, among, and between these layers of transverse fibres, and become visible, in front of the pons, as two broad diverging bundles, called *crura cerebri* (Fig. 84). Above the crura cerebri lies a mass of nervous matter raised up into four hemispherical elevations, called *corpora quadrigemina* (*C.Q.* Fig. 86). Between these and the crura cerebri is a narrow passage, which leads from the fourth ventricle into what is termed the *third ventricle* of the brain. The third ventricle is a narrow cavity lodged between two great masses of nervous matter, called *optic thalami*, into which the crura cerebri pass. The roof of the third ventricle is merely membranous; and a peculiar body of unknown function, the *pineal body*, is connected with it. The floor of the third ventricle is produced into a sort of funnel, which ends in another anomalous organ, the *pituitary body* (*Pt.* Fig. 86; *P.* Fig. 84).

The third ventricle is closed, in front, by a thin layer of nervous matter; but, beyond this, on each side, there is an aperture in the boundary wall of the third ventricle

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border of the *pons*; and coming forward in front of that line, between the *IV.* and *III.* nerves on either side, are seen the crura cerebri. The two round bodies in the angle between the diverging crura are the so-called *corpora albicantia*, and in front of them is *P*, the pituitary body. This rests on the chiasma, or junction, of the optic nerves; the continuation of each nerve is seen sweeping round the crura cerebri on either side. Immediately in front, between the separated frontal lobes of the cerebral hemispheres, is seen the corpus callosum, *CC*. The fissure of Sylvius, about on a level with *I.* on the left and *II.* on the right side, marks the division between frontal and temporal lobes.

which leads into a large cavity. The latter occupies the centre of the *cerebral hemisphere*, and is called the *lateral*

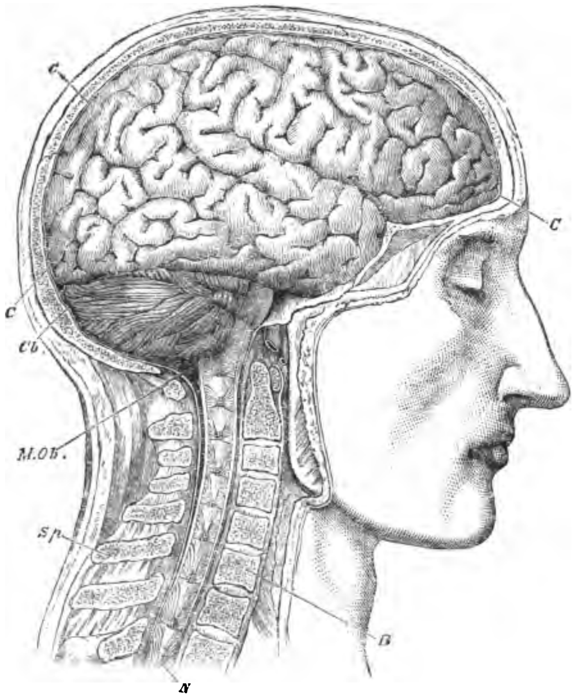

FIG. 85.

A side view of the brain and upper part of the spinal cord in place—the parts which cover the cerebro-spinal centres being removed. *C. C.* the convoluted surface of the right cerebral hemisphere; *Cb.* the cerebellum; *M.Ob.* the medulla oblongata; *B.* the bodies of the cervical vertebræ; *Sp.* their spines; *N.* the spinal cord with the spinal nerves.

ventricle. Each hemisphere is enlarged backwards, downwards and forwards, into as many *lobes*; and the

lateral ventricle presents corresponding prolongations, or *cornua.*

The floor of the lateral ventricle is formed by a mass of nervous matter, called the *corpus striatum*, into which the fibres of the crura cerebra that have passed by or traversed the optic thalamus enter (Fig. 86, *C.S.*).

The hemispheres are so large that they overlap all the other parts of the brain, and, in the upper view, hide them.

Their applied faces are separated by a median fissure for the greater part of their extent; but, inferiorly, are joined by a thick mass of transverse fibres, the *corpus callosum* (Fig. 84, *CC*).

The outer surfaces of the hemispheres are marked out into *convolutions*, or *gyri*, by numerous deep *fissures* (or *sulci*), into which the pia mater enters. One large and deep fissure which separates the anterior from the middle division of the hemisphere is called the *fissure of Sylvius* (Fig. 84).

17. In the *medulla oblongata* the arrangement of the white and grey matter is substantially similar to that which obtains in the spinal cord; that is to say, the white matter is external and the grey internal; but the grey matter, containing, as in the spinal cord, nerve cells, is more abundant than in the spinal cord, and the arrangements of white and grey matter become much more intricate and complex.

In the brain above the medulla oblongata there are internal deposits of grey matter, containing nerve cells, at various places, more especially in the pons Varolii, the crura cerebri, the corpora quadrigemina, optic thalami and corpora striata. And there is a remarkably shaped deposit of grey matter in the interior of the cerebellum, on each side. But what especially characterizes the brain is the presence of grey matter of a special nature, containing peculiarly shaped nerve cells, on the surface of the cerebral hemispheres, and on that of the cerebellum. This superficial grey matter covers the whole surface of both these organs, dipping down into the fissures (sulci) of the former, and following the peculiar plaits or folds into which the latter is thrown.

The fibres constituting the white matter of the brain

and connecting the various deposits of grey matter with each other and with the spinal cord, are arranged in a very complicated manner.

18. Nerves are given off from the brain in pairs, which succeed one another from before backwards, to the number of twelve (Fig. 86). These are often called "*cranial*" nerves, to distinguish them from the spinal nerves.

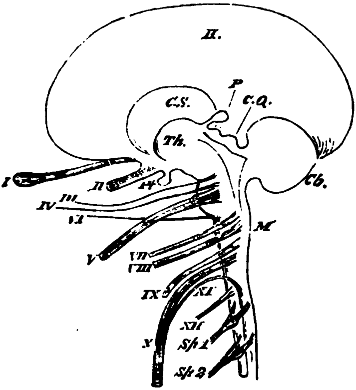

FIG. 86.—A DIAGRAM ILLUSTRATING THE ARRANGEMENT OF THE PARTS OF THE BRAIN AND THE ORIGIN OF THE NERVES.

H. the cerebral hemispheres; *C.S.* corpus striatum; *Th.* optic thalamus; *P.* pineal body; *Pt.* pituitary body; *C.Q.* corpora quadrigemina; *Cb.* cerebellum; *M.* medulla oblongata; *I.—XII.* the pairs of cerebral nerves; *Sp.* 1, *Sp.* 2, the first and second pairs of spinal nerves.

The *first pair*, counting from before backwards, are the *olfactory nerves*, and the *second* are the *optic* nerves. The functions of these have already been described.

The *third pair* are called *motores oculi* (movers of the eye), because they are distributed to all the muscles of the eye except two.

The nerves of the *fourth pair* and of the *sixth pair* supply, each, one of the muscles of the eye, on each side; the fourth going to the superior oblique muscle, and the

sixth to the external rectus. Thus the muscles of the eye, small and close together as they are, receive their nervous stimulus by three distinct nerves.

Each nerve of the *fifth pair* is very large. It has two roots, a motor and a sensory, and further resembles a spinal nerve in having a ganglion on its sensory root. It is the nerve which supplies the skin of the face and the muscles of the jaws, and, having three chief divisions, is often called *trigeminal*. One branch containing sensory fibres supplies the fore-part of the mucous membrane of the tongue, and is often spoken of as the *gustatory*.

The *seventh pair* furnish with motor nerves the muscles of the face, and some other muscles, and are called *facial*.

The *eighth pair* are the *auditory* nerves. As the seventh and eighth pairs of nerves leave the cavity of the skull together, they are often, and especially by English writers on anatomy, reckoned as one, divided into *portio dura*, or hard part (the facial); and *portio mollis*, or soft part (the auditory) of the "seventh" pair.

The *ninth pair* in order, the *glossopharyngeal*, are mixed nerves; each being, partly, a nerve of taste, and supplying the hind-part of the mucous membrane of the tongue, and, partly, a motor nerve for the pharyngeal muscles.

The *tenth pair* are the two *pneumogastric* nerves, often called the *par vagum*. These very important nerves, and the next pair, are the only cranial nerves which are distributed to regions of the body remote from the head. The pneumogastric supplies the larynx, the lungs, the liver, and the stomach, and branches of it are connected with the heart.

The *eleventh pair* again, called *spinal accessory*, differ widely from all the rest, in arising from the sides of the spinal marrow, between the anterior and posterior roots of the dorsal nerves. They run up, gathering fibres as they go, to the medulla oblongata, and then leave the skull by the same aperture as the pneumogastric and glossopharyngeal. They are purely motor nerves, supplying certain muscles of the neck, while the pneumogastric is mainly sensory, or at least afferent. As, on each side, the glossopharyngeal, pneumogastric, and spinal accessory nerves

leave the skull together, they are frequently reckoned as one pair, which is then counted as the *eighth*.

The last two nerves, by this method of counting, become the *ninth* pair, but they are really the *twelfth*. They are the motor nerves which supply the muscles of the tongue.

19. Of these nerves, the two foremost pair do not properly deserve that name, but are really processes of the brain. The olfactory pair are prolongations of the cerebral hemispheres; the optic pair, of the walls of the third ventricle; and it is worthy of remark, that it is only these two pairs of what may be called *false nerves* which arise from any part of the brain but the medulla oblongata or its immediate vicinity—all the other *true nerves* being indirectly, or directly, traceable to that part of the brain, while the olfactory and optic nerves are not so traceable.

20. As might be expected from this circumstance alone, the medulla oblongata is an extremely important part of the cerebro-spinal axis, injury to it giving rise to immediate evil consequences of the most serious kind.

Simple puncture of one side of the floor of the fourth ventricle produces for a while an increase of the quantity of sugar in the blood, beyond that which can be utilized by the organism. The sugar passes off by the kidneys, and thus this slight injury to the medulla produces a temporary disorder closely resembling the disease called *diabetes*.

More extensive injury arrests the respiratory processes, the medulla oblongata being as we have seen (Lesson IV. § 24), the nervous centre which gives rise to the contractions of the respiratory muscles and keeps the respiratory pump at work.

And the heart may be stopped, for a time at least, by irritation of the fibres of the pneumogastric nerve at their origin in the medulla (see Lesson II. § 27).

We have just seen (§ 15) that the medulla oblongata acts as an important centre for the vaso-motor nerves. It is also a nervous centre for the act of swallowing, for the secretion of saliva, and for many other actions. And when we remember that every impulse, afferent or efferent, passing between the higher parts of the brain, and every nerve of the body, with the exception of the optic, olfactory (and perhaps the third and fourth eye nerves), must

make its way through some part or other of the medulla oblongata, the importance of this organ becomes obvious.

21. It is a singular fact that when one side of the brain is diseased or injured, the effects are visible on the other side of the body. Thus when, as not unfrequently happens, a blood-vessel gives way in the right cerebral hemisphere, leading to a destruction of nervous matter there, the result is that the left arm, and left leg, and left side of the body generally are paralysed, that is, the will has no longer any power to move the muscles of that side, and impulses started in the skin of that side cannot awaken sensations in the brain. Hence, it is said that between the brain and the peripheral organs there is a complete crossing or *decussation* of efferent (voluntary) and afferent (sensory) impulses. We have already seen (§ 14) that a certain amount of crossing of impulses of both kinds takes place all along the spinal cord ; but the chief decussation seems to take place in the medulla oblongata, and is probably largely, though not wholly, effected by means of what is called the *decussation of the anterior pyramids* (see Fig. 84). Here, large bundles of fibres coming chiefly from the lateral columns of the spinal cord (which as we have seen (§ 14) seem to be the chief channels for the conduction of sensory and motor impulses along the cord), rise up to the front and cross over to the other side.

But there is also a decussation of impulses in the case of the nerves arising from the medulla above the decussation of the pyramids. Thus, in the case quoted above of a blood vessel bursting in the right cerebral hemisphere, the left side of the man's face is paralysed as well as the left side of his body, that is to say, impulses cannot pass to and from his brain and the left facial and fifth nerves. The impulses along these nerves cross over, decussate, and reach the right side of the brain.

It sometimes happens, however, that disease or injury may affect the medulla oblongata itself, on one side only (*e.g.* the right), above the decussation of the pyramids, in such a way that the fifth and facial nerves are affected in their course before they decussate, that is to say, on the same side as the injury. The man then,

while still paralysed on the left side of his body, is paralysed on the right side of his face.

22. The functions of most of the parts of the brain which lie in front of the medulla oblongata are, at present, very ill understood; but it is certain that extensive injury, or removal, of the cerebral hemispheres puts an end to intelligence and voluntary movement, and leaves the animal in the condition of a machine, working by the reflex action of the remainder of the cerebro-spinal axis.

We have seen that in the frog the movements of the body which the spinal cord alone, in the absence of the whole of the brain, including the medulla oblongata, is capable of executing, are of themselves strikingly complex and varied. But none of these movements arise from changes originating within the organism, they are not what are called voluntary or spontaneous movements; they never occur unless the animal be stimulated from without. Removal of the cerebral hemispheres is alone sufficient to deprive the frog of all spontaneous or voluntary movements; but the presence of the medulla oblongata and other parts of the brain (such as the corpora quadrigemina, or what corresponds to them in the frog, and the cerebellum) renders the animal master of movements of a far higher nature than when the spinal cord only is left. In the latter case the animal does not breathe when left to itself, lies flat on the table with its fore-limbs beneath it in an unnatural position; when irritated kicks out its legs, and may be thrown into actual convulsions, but never jumps from place to place; when thrown into a basin of water falls to the bottom like a lump of lead, and when placed on its back will remain so, without making any effort to turn over. In the former case the animal sits on the table, resting on its front limbs, in the position natural to a frog; breathes quite naturally; when pricked behind jumps away, often getting over a considerable distance; when thrown into water begins at once to swim, and continues swimming until it finds some object on which it can rest; and when placed on its back immediately turns over and resumes its natural position. Not only so, but the following very striking experiment may be performed with it. Placed on a small board it remains perfectly motionless so long as the board is

horizontal; if, however, the board be gradually tilted up so as to raise the animal's head, directly the board becomes inclined at such an angle as to throw the frog's centre of gravity too much backwards, the creature begins slowly to creep up the board, and, if the board continues to be inclined, will at last reach the edge, upon which when the board becomes vertical he will seat himself with apparent great content. Nevertheless, though his movements when they do occur are extremely well combined and apparently identical with those of a frog possessing the whole of his brain, he never moves spontaneously, and never stirs unless irritated.

Thus the parts of the brain below the cerebral hemispheres constitute a complex nervous machinery for carrying out intricate and orderly movements, in which afferent impulses play an important part, though they do not give rise to clear or permanent affections of consciousness.

23. There can be no doubt that the cerebral hemispheres are the seat of powers, essential to the production of those phenomena which we term intelligence and will; and there is experimental and other evidence which seems to indicate a connection between particular parts of the surface of the cerebral hemispheres, and particular acts. Thus irritation of particular spots in the anterior part of a dog's brain will give rise to particular movements of this or that limb, or of this or that group of muscles; and the destruction of a certain part of the posterior lobes of the cerebral hemispheres is said to cause blindness. But the exact way in which these effects are brought about is not yet thoroughly understood; and even if it should be ultimately proved beyond all doubt, that the central end-organ of vision (Lesson VIII. § 28) consists of certain nerve-cells lying in a particular part of the posterior surface of the cerebral hemisphere, and that the central end-organ of hearing consists of other nerve-cells lying elsewhere on the cerebral surface, it will still leave us completely in the dark as to what goes on in the cerebral hemispheres when we think and when we will.

There is no doubt that a molecular change in some part of the cerebral substance is an indispensable antecedent to every phenomenon of consciousness. And it is

possible that the progress of investigation may enable us to map out the brain according to the psychical relations of its different parts. But supposing we get so far as to be able to prove that the irritation of a particular fragment of cerebral substance gives rise to a particular state of consciousness, the reason of the connection between the molecular disturbance and the psychical phenomenon appears to be out of the reach, not only of our means of investigation, but even of our powers of conception.

24. Even while the cerebral hemispheres are entire, and in full possession of their powers, the brain gives rise to actions which are as completely reflex as those of the spinal cord.

When the eyelids wink at a flash of light, or a threatened blow, a reflex action takes place, in which the afferent nerves are the optic, the efferent the facial. When a bad smell causes a grimace, there is a reflex action through the same motor nerve, while the olfactory nerves constitute the afferent channels. In these cases, therefore, reflex action must be effected through the brain, all the nerves involved being cerebral.

When the whole body starts at a loud noise, the afferent auditory nerve gives rise to an impulse which passes to the medulla oblongata, and thence affects the great majority of the motor nerves of the body.

25. It may be said that these are mere mechanical actions, and have nothing to do with the operations which we associate with intelligence. But let us consider what takes place in such an act as reading aloud. In this case, the whole attention of the mind is, or ought to be, bent upon the subject-matter of the book; while a multitude of most delicate muscular actions are going on, of which the reader is not in the slightest degree aware. Thus the book is held in the hand, at the right distance from the eyes; the eyes are moved from side to side, over the lines and up and down the pages. Further, the most delicately adjusted and rapid movements of the muscles of the lips, tongue, and throat, of the laryngeal and respiratory muscles, are involved in the production of speech. Perhaps the reader is standing up and accompanying the lecture with appropriate gestures. And yet every one of these muscular acts may be performed with utter

unconsciousness, on his part, of anything but the sense of the words in the book. In other words they are reflex acts.

26. The reflex actions proper to the spinal cord itself are *natural*, and are involved in the structure of the cord and the properties of its constituents. By the help of the brain we may acquire an infinity of *artificial* reflex actions, that is to say, an action may require all our attention and all our volition for its first, or second, or third performance, but by frequent repetition it becomes, in a manner, part of our organization, and is performed without volition, or even consciousness.

As everyone knows, it takes a soldier a long time to learn his drill—for instance, to put himself into the attitude of "attention" at the instant the word of command is heard. But, after a time, the sound of the word gives rise to the act, whether the soldier be thinking of it, or not. There is a story, which is credible enough, though it may not be true, of a practical joker, who, seeing a discharged veteran carrying home his dinner, suddenly called out "Attention!" whereupon the man instantly brought his hands down, and lost his mutton and potatoes in the gutter. The drill had been thorough, and its effects had become embodied in the man's nervous structure.

The possibility of all education (of which military drill is only one particular form) is based upon the existence of this power which the nervous system possesses, of organizing conscious actions into more or less unconscious, or reflex, operations. It may be laid down as a rule, which is called the Law of Association, that if any two mental states be called up together, or in succession, with due frequency and vividness, the subsequent production of the one of them will suffice to call up the other, and that whether we desire it or not.

The object of intellectual education is to create such indissoluble associations of our ideas of things, in the order and relation in which they occur in nature; that of a moral education is to unite as fixedly the ideas of evil deeds with those of pain and degradation, and of good actions with those of pleasure and nobleness.

27. The *sympathetic system* consists chiefly of a double chain of ganglia, lying at the sides and in front of the

spinal column, and connected with one another, and with the spinal nerves, by commissural cords. From these ganglia, nerves are given off which for the most part follow the distribution of the vessels, but which, in the thorax and abdomen, form great networks, or *plexuses*, upon the heart and about the stomach and other abdominal viscera. A great number of the fibres of the sympathetic system are derived from the spinal cord; but others originate in the ganglia of the sympathetic itself.

By means of the sympathetic nerves the muscles of the vessels generally, and those of the heart, of the intestines, and of some other viscera may, as we have seen, be influenced; and the influence thus conveyed, it may be remarked, is generally different to, or even antagonistic to that which is conveyed to the same organs by the fibres running in the spinal or cranial nerves. Thus while irritation of the (cranial) pneumogastric fibres stops the heart, irritation of the sympathetic fibres going to the heart increases the beat.

But the influences which thus reach these organs through the sympathetic nerves, do not seem to originate in the sympathetic system itself, but to be derived from the spinal cord or brain. We have seen (§ 14) this to be the case in reference to vaso-motor nerves, and the same is true of the sympathetic nerves going to the heart and other viscera. Whatever may turn out to be the function of the sympathetic ganglia, there is at present no adequate evidence that they in any way act as nervous centres, either of reflex action, or of any other form of nervous activity.

LESSON XII.

HISTOLOGY; OR, THE MINUTE STRUCTURE OF THE TISSUES.

1. In the first chapter (§ 11) attention was directed to the obvious fact that the substance of which the body of a man or other of the higher animals is composed, is not of uniform texture throughout; but that, on the contrary, it is distinguishable into a variety of components which differ very widely from one another, not only in their general appearance, their colour, and their hardness or softness, but also in their chemical composition, and in the properties which they exhibit in the living state.

In dissecting a limb there is no difficulty in distinguishing the bones, the cartilages, the muscles, the nerves and so forth from one another; and it is obvious that the other limbs, the trunk, and the head, are chiefly made up of similar structures. Hence, when the foundations of anatomical science were laid, more than two thousand years ago, these "like" structures which occur in different parts of the organism were termed *homoiomera*, "similar parts." In modern times they have been termed "tissues," and the branch of biology which is concerned with the investigation of the nature of these tissues is called *Histology*.

Histology is a very large and difficult subject, and this whole book might well be taken up with a thorough discussion of even its elements. But physiology is, in ultimate analysis, the investigation of the vital properties

of the histological units of which the body is composed. And even the elements of physiology cannot be thoroughly comprehended without a clear apprehension of the nature and properties of the principal tissues.

2. A good deal may be learned about the tissues without other aid than that of the ordinary methods of anatomy, and it is extremely desirable that the student should acquire this knowledge as a preliminary to further inquiry. But the chief part of modern histology is the product of the application of the microscope to the elucidation of the minute structure of the tissues; and this has had the remarkable result of proving that these tissues themselves are made up of extremely small *homoiomera*, or similar parts, which are primitively alike in form in all the tissues.

3. Every tissue therefore is a compound structure: a multiple of histological units, or an aggregation of histological elements; and the properties of the tissue are the sum of the properties of its components.

The distinctive character of every fully formed tissue depends on the structure, mode of union, and vital properties of its histological elements when they are fully formed. But each tissue can be traced back to a young or embryonic condition, in which it has no characteristic properties, and in which its histological elements are so similar in structure, mode of union, and vital properties to those of every other embryonic tissue, that our present means of investigation do not enable us to discover any difference among them.

4. These embryonic, undifferentiated, histological elements, of which every tissue is primitively composed, or, as it would be more correct to say, which, in the embryonic condition, occupy the place of the tissues, are technically named *nucleated cells*. The colourless blood corpuscle (Lesson III. § 6) is a typical representative of such a cell. And it is substantially correct to say (1) that the histological elements of every tissue are modifications or products of such cells; (2) that every tissue was once a mass of such cells more or less closely packed together; and (3) that the whole embryonic body was at one time nothing but an aggregation of such cells.

5. The body of a man or of any of the higher animals

in fact commences as an ovum or egg. This (Fig. 87) is a minute transparent spheroidal sac, $\frac{1}{120}$ of an inch in diameter in man, which contains a similarly spheroidal mass of protoplasm, in which a single large nucleus is imbedded.

The first step towards the production of all the complex organization of a mammal out of this simple body is the division of the nucleus into two new nuclei which recede from one another, while at the same time the protoplasmic body becomes separated, by a narrow cleft which runs between the two nuclei, into two masses, or *blastomeres*, (Fig. 88) one for each nucleus. By the repetition of the process the two blastomeres give rise to four, the four to eight, the eight to sixteen, and so on, until the embryo is

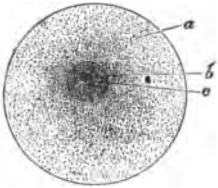

FIG. 87.—DIAGRAM OF THE OVUM.
a, Granular protoplasm; *b*, nucleus, called "germinal vesicle;" *c*, nucleolus, called "germinal spot."

an aggregate of numerous small blastomeres, or nucleated cells. These grow at the expense of the nutriment supplied from without, and continue to multiply by division according to the tendencies inherent in each until, long before any definite tissue has made its appearance, they build themselves up into a kind of sketch model of the developing animal, in which model many of, if not all the future organs are represented by mere aggregates of undifferentiated cells.

6. Gradually, these undifferentiated cells become changed into groups or sets of differentiated cells, the cells in one set being like each other, but unlike those of other sets. Each set of differentiated cells constitutes a "tissue," and each tissue is variously distributed among the several

organs, each organ generally consisting of more than one tissue.

And this differentiation in structure is accompanied by a change of properties. The undifferentiated cells are, as far as we can see, alike in function and properties as they are alike in structure. But coincident with their differentiation into tissues, a division of labour takes place, so that in one tissue the cells manifest special properties

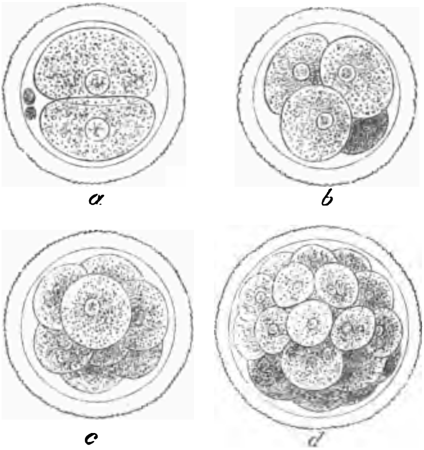

FIG. 88.—THE SUCCESSIVE DIVISION OF THE MAMMALIAN OVUM INTO BLASTOMERES. Somewhat diagrammatic.

a, division into two; *b*, into four; *c*, into eight, and *d*, into several blastomeres. The clear ring seen in each case is the *zona pellucida*, or membrane investing the ovum.

and carry on a special work; in another they have other properties, and other work; and so on.

The principal tissues into which the undifferentiated cells of the embryo become differentiated, and which are variously built up into the organs and parts of the adult body, may be arranged as follows.

(1.) The most important tissues are the *muscular* and

nervous tissues, for it is by these that the active life of the individual is carried on.

(2.) Next come the *epithelial* tissues, which, on the one hand, afford a covering for the surface of the body as well as a lining for the various internal cavities of the body: and, on the other hand, carry on a great deal of the chemical work of the body, inasmuch as they form the essential part of the various glandular organs of the body.

(3.) The remaining principal tissues of the body, namely the so-called *connective* tissue, *cartilaginous* tissue and *osseous* or *bony* tissue, form a group by themselves, being all three similar in their fundamental structure, and all three being, for the most part, of use to the body for their passive rather than for their active qualities. They chiefly serve to support and connect the other tissues.

These principal or fundamental tissues are often arranged together to form more complex parts of the body, which are sometimes spoken of, though in a different sense, as tissues. Thus various forms of connective tissue are built up with some muscular tissue and nervous tissue, to form the blood-vessels of the body (see Lesson II.), which are sometimes spoken of as "vascular tissue." So again, a certain kind of epithelial tissue, known as "epidermis," together with connective tissue, blood-vessels and nerves, forms the skin or tegumentary tissue; a similar combination of epithelium with other tissues constitutes the mucous membrane lining the alimentary canal, and also occurs in the so-called "glandular" tissue.

We may confine our attention here to the principal tissues properly so-called.

7. *Epithelial tissue.* A good example of this tissue is to be found in the epidermis of the skin, which, as we have seen (Lesson V.), consists of the superficial epidermis which is non-vascular and epithelial in nature, and of the deep derma, which is vascular, and is indeed chiefly composed of connective tissue carrying blood-vessels and nerves. And in all the mucous membranes there is a similar superficial epithelial layer, which is here simply called epithelium, and a deep layer, which similarly consists of connective tissue carrying blood-vessels and nerves and may also be spoken of as derma.

8. If a piece of fresh skin is macerated for some time in

water, it will be easy to strip off the epidermis from the derma.

The outer part of the epidermis which has been detached by maceration will be found to be tolerably dense and coherent, while its deep or inner substance is soft and almost gelatinous. Moreover, this softer substance fills up all the irregularities of the surface of the derma to which it adheres, and hence, where the derma is raised up into papillæ, the deep or under surface of the epidermis presents innumerable depressions into which the papillæ fit, giving it an irregular appearance, somewhat like a network. Hence it used not unfrequently to be called the *network of Malpighi* (*rete Malpighii*), after a great Italian anatomist of the seventeenth century, who first properly described it. On the other hand, its soft and gelatinous character led to its being called mucous layer (*stratum mucosum*). Chemical analysis shows that the firm outer layer of the epidermis differs from the deep soft part by containing a great deal of horny matter. Hence this is distinguished as the *horny* layer (*stratum corneum*).

In the living subject the superficial layers of the epidermis become separated from the lower layers and the derma, when friction or other irritation produces a "blister." Fluid is poured out from the vessels of the derma, and, accumulating between the upper and lower layers of the epidermis, detaches the latter.

9. The epidermis is constantly growing upon the deep or dermic side in such a manner that the horny layer is continually being shed and replaced. The "scurf" which collects between the hairs and on the whole surface of the body, and is removed by our daily brushing and washing, is nothing but shed epidermis. When a limb has been bandaged up and left undisturbed for weeks, as in case of a fracture, the shed epidermis collects on the surface of the skin in the shape of scales and flakes, which break up into a fine white powder when rubbed. Thus we "shed our skins" just as snakes do, only that the snake sheds all his dead epidermis as a coherent sheet at once, while we shed ours bit by bit, and hour by hour.

10. What is the nature of the process by which the epidermis is continually removed?

If a little of the epidermic scurf is mixed with water

and examined under a power magnifying 300 or 400 diameters, it will seem to consist of nothing but irregular particles of very various sizes and with no definite structure. But if a little caustic potash or soda is previously added to the water the appearance will be changed. The caustic alkali causes the horny substance to swell up and become transparent; and this is now seen to consist of minute separable plates, some of which contain a rounded body in the interior of the plate, though in many this is no longer recognisable. In fact, so far as their form is concerned, these bodies have the character of nucleated cells, in which the protoplasmic body has been more or less extensively converted into horny substance.

Thus the cast-off epidermis in reality consists of more or less coherent masses of cornified nucleated cells.

There is a yet simpler method of demonstrating this truth. At the margins of the lips the epidermis is continued into the interior of the mouth, and though it now receives the name of epithelium it differs from the rest of the skin in no essential respect except that it is very thin, and allows the blood in the vessels of the subjacent derma to shine through. Let the lower lip be turned down, its surface very gently scraped with a blunt-edged knife, and the substance removed be spread out, and covered with a thin glass, and examined as before. The whole field of view will then be seen to be spread over with flat irregular bodies very like the epidermic scales, but more transparent, and each provided with a nucleus in its centre (Fig. 89).

Since these detached scales are always to be found on the inner surface of the lip, it follows that they are always being thrown off.

10. The horny external layer of the epidermis, then, is composed of coherent cornified flattened cells, which are constantly becoming detached from the soft internal layer, and must needs be, in some way, derived from it. But in what way? Here microscopic investigation furnishes the answer. For if the soft layer is properly macerated it breaks up into small masses of nucleated protoplasmic substance, that is, into nucleated cells which in the innermost or deepest part of the layer

are columnar in form, being elongated perpendicularly to the face of the derma, on which they rest, and which in the intermediate region present transitions in form and other respects between these and the shed scales.

A thin vertical section of epidermis (Fig. 90) in undisturbed relation with the subjacent derma, leaves not the smallest doubt (*a*) that the epidermis consists of nothing but nucleated cells, with perhaps an infinitesimal amount of cementing substance between them; (*b*) that from the deep to the superficial part of the derma, the cells always present a succession from columnar or sub-cylindrical protoplasmic forms to flattened completely cornified forms. And since we know that the latter are

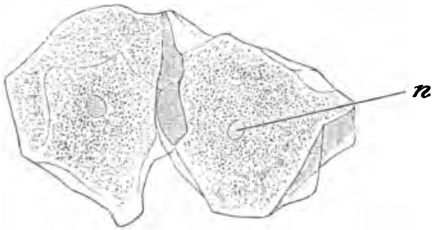

FIG. 89.—TWO EPITHELIAL SCALES FROM THE INTERIOR OF THE MOUTH. A small nucleus *n* is seen in each, as well as fine granulations in the body of the plate. The edges of the plates are irregular from pressure. Magnified about 400 times.

constantly being thrown off, it follows (*c*) that these gradations of form represent cells of the deep layer which are continually passing to the surface, and being thrown off there.

11. What is the cause of this constant succession? To this question, also, microscopic investigation furnishes a clear answer. The deeper cells are constantly growing and then multiplying by a process of division in such a manner that the nucleus of a cell divides into two new nuclei, around each of which one half of the protoplasmic body disposes itself. Thus one cell becomes two, and each of these grows until it acquires its full size at the expense of the nutritive matters which exude from the

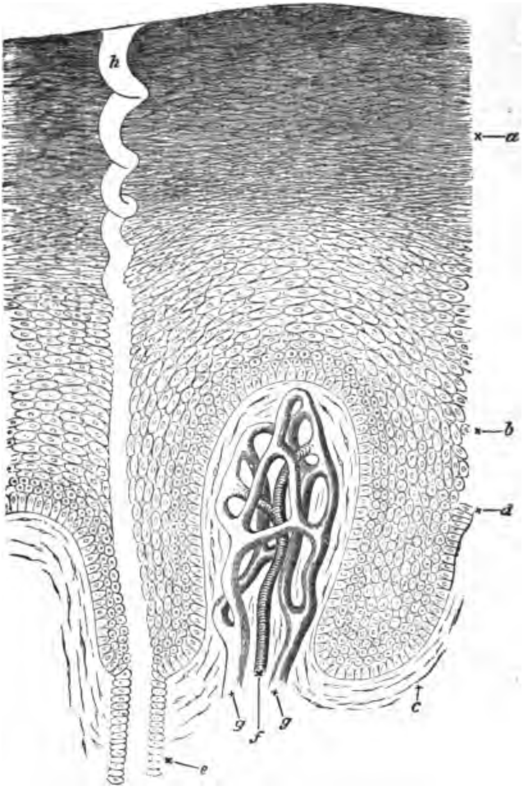

FIG. 90.

Section of skin highly magnified—somewhat diagrammatic. *a*, horny epidermis; *b*, softer layer, *rete Malpighii*; *c*, dermis; *d*, lowermost vertical layer of epidermic cells; *e*, cells lining the sweat duct continuous with epidermic cells; *h*, corkscrew canal of sweat duct. To the right of the sweat duct the dermis is raised into a papilla, in which the small artery, *f*, breaks up into capillaries, ultimately forming the veins, *g*.

vessels with which the derma is abundantly supplied; such a cell in fact possesses the vital properties of a primitive embryo cell.

The cells nearer the derma are more immediately and abundantly supplied with nourishment from the dermal blood-vessels, and serve as the focus of growth and multiplication for the whole epidermis; they are in fact the progenitors of the superficial cells which, as they are thrust away by the intercalation of new cells between the last formed and the progenitors, become metamorphosed in form and chemical character, and at last die and are cast off.

And it follows that the epidermis is to be regarded as a compound organism made up of myriads of cells, each of which follows its own laws of growth and multiplication, and is dependent upon nothing save the due supply of nutriment from the dermal vessels. The epidermis, so far, stands in the same relation to the derm as does the turf of a meadow to the subjacent soil.

12. Structures which are rendered clearly distinguishable only by a magnifying power of 300 or 400 diameters must needs be very small, and it is desirable that, before going any further, the learner should try to form a definite notion of their actual and relative dimensions by comparison with more familiar objects. A hair of the human head of ordinary fineness has a diameter of about $\frac{1}{300}$th (say 0·003) of an inch, or 0·08 mm. (millimetre). The hairs which constitute the fur of a rabbit, on the other hand, are very much finer, and the thickest part of the shaft usually does not exceed $\frac{1}{1000}$th of an inch, *i.e.* 0·001 inch or about 0·025 mm.; while the fine point of such a hair may be as little as $\frac{1}{25000}$th of an inch, about 0·001 mm., or even less in diameter.

In microscopic histological investigations the range of the magnitudes with which we have to do ordinarily lies between 0·1 and 0·001 millimetre; that is to say roughly between one two hundred and fiftieth and one twenty-five thousandth of an inch. It is therefore extremely convenient to adopt, as a unit of measurement, 0·001 millimetre, called a micro-millimetre, and indicated by the symbol μ, of which all greater magnitudes are multiples. Thus, if the extreme point of a rabbit's hair has a diameter of 1μ,

the middle of the shaft will be 25μ, and the shaft of a human head hair 80μ.

Adopting this system, the deep cells of epidermis have on an average a diameter of 12μ or more, the nuclei of 4μ to 5μ, while the superficial cells are plates of about 25μ, the nuclei retaining about the same dimensions. The diameter of a white corpuscle of the blood is about 10μ, that of a red corpuscle being 7μ to 8μ. Hence the deep cells of the epidermis are rather larger than white blood corpuscles, and the uppermost ones much larger, at least in superficial area.

13. The epidermis proper everywhere presents substantially the same general characters. Its permeability to water permits, as we have seen, of the transudation of the insensible perspiration, and it thus plays the part of an *excretory* organ, while, in so far as it continually forms and throws off cornified cells, it might be said to *secrete* horny matter.

But in many parts of the body the excretory functions of the skin are concentrated and intensified by a very simple modificatio of the epidermis, which is produced inwards into saccular or tubular pouches. These are the so-called *cutaneous glands* which are of two kinds—*sweat glands* and *sebaceous glands.*

The swea glands, as we have seen (Lesson V.), are long tubes, the inner ends of which lie deep in the derma and are coiled up and surrounded by a rich network of capillary vessels. (See Figs. 31, 33, pp. 121, 123, and Fig. 90.)

The sebaceous glands have rather the form of short sacculated pouches; and the substance of their cells undergoes chemical metamorphosis, not into horny but into fatty matter, which, as the cells are thrown off and burst, is poured out through the neck or duct of the pouch.

14. In other regions the cornified cells are not at once thrown off in flakes, but are at first built up in definite structures known as *nails* and *hairs*, which grow by constant addition to the surfaces by which they adhere to the epidermis. In the case of the nails, the process of growth has no limit, and the nail is kept of one size simply by the wearing away of its oldest or free end. In the case of the hairs, on the contrary, the growth of each hair

is limited, and when its term is reached the hair falls out and is replaced by a new hair.

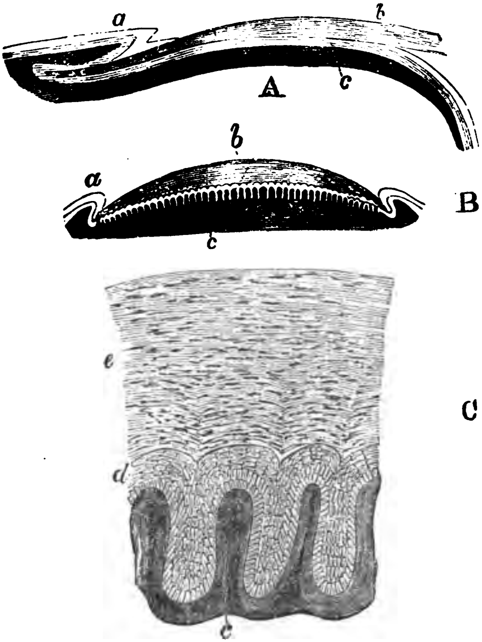

FIG. 91.

A, a longitudinal and vertical section of a nail: *a*, the fold at the base of the nail; *b*, the nail; *c*, the bed of the nail. The figure B is a transverse section of the same—*a*, a small lateral fold of the integument; *b*, nail; *c*, bed of the nail, with its ridges. The figure C is a highly-magnified view of a part of the foregoing—*c*, the ridges; *d*, the deep layers of epidermis; *e*, the horny scales coalesced into nail substance. (Figs. A and B magnified about 4 diameters; Fig. C magnified about 200 diameters.)

15. Underneath each *nail* the deep or *dermic* layer of the integument is peculiarly modified to form the *bed of*

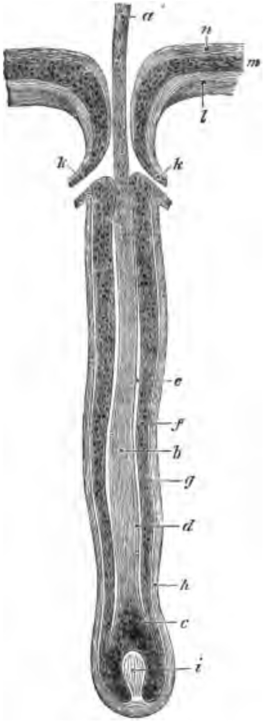

FIG. 92.—A HAIR IN ITS HAIR-SAC.

a, shaft of hair above the skin; *b*, cortical substance of the shaft, the medulla not being visible; *c*, newest portion of hair growing on the papilla (*i*); *d*, cuticle of hair; *e*, cavity of hair-sac; *f*, epidermis (and root-sheaths) of the hair-sac corresponding to that of the integument (*m*); *g*, division between dermis and epidermis; *h*, dermis of hair-sac corresponding to dermis of integument (*l*); *k*, mouths of sebaceous glands; *n*, horny epidermis of integument.

the nail. It is very vascular, and raised up into numerous parallel ridges, like elongated papillæ (Fig. 91, B, C).

The surfaces of all these are covered with growing epidermic cells, which, as they flatten and become converted into horn, form a solid continuous plate, the nail. At the hinder part of the bed of the nail the integument forms a deep fold, from the bottom of which, in like manner, new epidermic cells are added to the base of the nail, which is thus constrained to move forward.

The nail, thus constantly receiving additions from below and from behind, slides forwards over its bed, and projects beyond the end of the finger, where it is worn away or cut off.

16. A *hair*, like a nail, is composed of horny cells; but instead of being only partially sunk in a fold of

FIG. 93.

Part of the shaft of a hair inclosed within its root-sheaths and treated with caustic soda, which has caused the shaft to become distorted.—*a*, medulla; *b*, cortical substance; *c*, cuticle of the shaft; from *d* to *f*, the root-sheaths, in section. (Magnified about 200 diameters.)

the integument, it is at first wholly enclosed in a kind of bag, the *hair-sac*, from the bottom of which a papilla (Fig. 92 *i*), which answers to a single ridge of the nail, arises. The hair is developed by the conversion into horn, and coalescences into a *shaft*, of the superficial epidermic cells coating the papilla. These coalesced and cornified cells being continually replaced by new growths from below, which undergo the same metamorphosis, the shaft of the hair is thrust out until it attains the full length natural to it. Its base then ceases to grow, and the old papilla and sac die away, but not before a new sac and papilla have been formed by budding from the sides of the old one. These give rise to a new hair. The shaft of a hair of the head consists of a central pith, or *medullary* matter, of a loose

and open texture, which sometimes contains air; of a *cortical* substance surrounding this, made up of coalesced elongated horny cells; and of an outer *cuticle*, composed of flat horny plates, arranged transversely round the shaft, so as to overlap one another by their outer edges, like closely-packed tiles. The superficial epidermic cells of the hair-sac also coalesce by their edges, and become converted into *root-sheaths*, which embrace the root of the hair, and usually come away with it when it is plucked out.

17. The mucous membrane lining the alimentary canal, as has been stated, is framed on the plan of the skin, inasmuch as it consists of a vascular derma, and a non-vascular epithelium, the latter being composed of cells in juxtaposition. But except in the region of the mouth, where as we have seen the epithelium, like the epidermis, is composed of many layers of cells, arranged as a soft Malpighian layer and a hard corneous layer, and the œsophagus where the structure is similar, the epithelium of the alimentary canal and the continuations of that epithelium into the ducts and alveoli of the various glands, consists of hardly more than a single layer of cells placed side by side. Hence in a vertical section of the mucous membrane the vascular derma is seen to be covered by a single row of soft nucleated cells; though sometimes a second row of inconspicuous small cells may be seen below the latter. The cells constituting this single layer vary in shape, being cylindrical or conical or, as especially in the glands, cubical or spheroidal; but they always are delicate masses of protoplasm, each containing a nucleus. The polygonal hepatic cells (see Lesson V.), are in reality the epithelium cells belonging to the minute biliary canals passing between them.

In the trachea and bronchi, the epithelium of the mucous membrane consists again of several layers of cells, but all are soft and protoplasmic nucleated masses, the uppermost layer being cylindrical in form and ciliated. In the ureter and bladder the epithelium also consists of several layers of cells which are frequently irregular in form.

Lastly, the blood-vessels and lymphatic vessels and the large serous cavities, such as the peritoneal and pleural

cavities, are lined by a peculiar epithelium, different in origin from the epithelium of the skin and mucous membranes. It consists of a single layer of flat, nucleated plates cemented together at their edges. The form of the plate or cell varies, being sometimes polygonal, sometimes spindle-shaped, and sometimes quite irregular.

18. A second group of tissues, of which cartilage may be taken as the simplest form and the type, differs from epithelium in a very essential feature. In epithelium, wherever it is found, the cells are placed close together, and the amount of material existing between the cells or *intercellular material* is exceedingly small. In the group of tissues, however, to which cartilage belongs, a very considerable quantity of intercellular material is, as we shall see, developed between the individual nucleated protoplasmic cells. Hence the cells are, more or less distinctly imbedded in a substance different from themselves and called a *matrix*. In epithelium, though the cells are sometimes joined together by a cement material, this is never abundant enough to deserve the name of matrix.

19. *Cartilage.*—Characteristic specimens of this tissue are to be found in the "sterno-costal cartilages," which unite many of the ribs with the breastbone. A thin but tough layer of vascular connective tissue invests, and closely adheres to, the surface of the cartilage. It is termed the *perichondrium*. The substance of the cartilage itself is devoid of vessels; it is hard, but not brittle, for it will bend under pressure; and moreover it is elastic, returning to its original shape when the pressure is removed. It may be easily cut into very thin slices, which are as transparent as glass, and to the naked eye appear homogeneous. Dilute acids and alkalies have no effect upon it in the cold; but if it is boiled in water, it yields a substance similar to gelatine, but somewhat different from it, which is called *chondrine*.

The sterno-costal cartilages of an adult man are many times larger than are those of an infant. It follows that these cartilages must grow. The only source from whence they can derive the necessary nutritive material is the plasma exuded from the blood contained in the vessels of the perichondrium. The vascular perichondrium therefore stands in the same relation to the non-vascular cartila-

ginous tissue as the vascular derma does to the non-vascular epidermis. But, since the cartilage is invested on all sides by the perichondrium, it is clear that no part of the cartilage can be shed in the fashion that the superficial layers of epidermis are got rid of. As the nutritive materials, at the expense of which the cartilage grows, are supplied from the perichondrium, it might be concluded that the cartilage grows only at its surface. But if a piece of cartilage is placed in a staining fluid, it will be found that it soon becomes more or less coloured throughout. In spite of its density, therefore, cartilage is very permeable, and hence the nutritive plasma also may permeate it, and enable every part to grow.

20. If a thin section of perfectly fresh and living cartilage is placed on a glass slide, either without addition or with only a little serum, it appears to the naked eye, as has been said, to be as homogeneous as a piece of glass. But the employment of an ordinary hand magnifier is sufficient to show that it is not really homogeneous, inasmuch as minute points of less transparency are seen to be scattered singly or in groups throughout the thickness of the section. When the section is examined with the microscope (Fig. 94) these points prove to be nucleated cells, varying in shape, but generally more or less spheroidal, sometimes far apart, sometimes very near, or even in contact with one another, in which last case the applied sides are flat. Usually each cell has a single nucleus, but sometimes there are two nuclei in a cell. And sometimes globules of fat appear in the protoplasmic bodies of the cells, and may completely fill them.

As a rule each cell lies in, and exactly fills, a cavity in the transparent matrix, or *intercellular substance*, which constitutes the chief mass of the tissue. But a pair of closely opposed flattened cells may occupy only one cavity, and all sorts of gradations may be found between hemi-spheroidal cells in contact, and hemi-spheroidal cells separated by a mere film of intercellular substance, and widely separate spheroidal, ellipsoidal, or otherwise shaped cells. In size, the cells vary very much, some being as small as 10μ, and others as large as 50μ, or even larger.

As the cartilage dies, and especially if water is added to it, the protoplasmic bodies of the cells shrink and

become irregularly drawn away from the walls of the cavities which contain them, and the appearance of the tissue is greatly altered.

No structure is discernible in the matrix or intercellular substance under ordinary circumstances; but it may be split up into thin sheets or laminæ. The portions of matrix immediately surrounding the several cavities sometimes differ in appearance and nature from the rest of

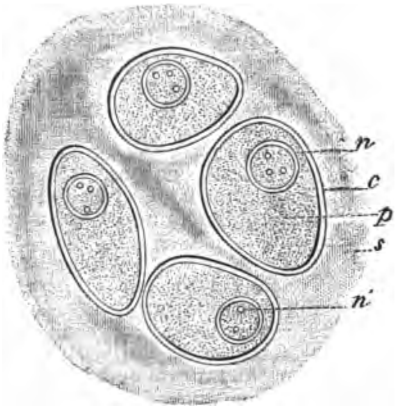

FIG. 94.—A SMALL PORTION OF A SECTION OF ARTICULAR CARTILAGE (FROG) VERY HIGHLY MAGNIFIED (600 diam.).

s, matrix or intercellular substance; *p*, the protoplasmic body of the cartilage corpuscle; *n*, its nucleus, with *n'*, nucleoli; *c*, the capsule, or wall of the cavity in which the cartilage corpuscle lies. The four cells here figured seem to have arisen from a single cell, by division, first into two and then into four. The shading of the matrix in an oblique line indicates the earlier division into two.

the matrix, so as to constitute distinct *capsules* (Fig. 94, *c*) for the cells; and, at times, the matrix may by appropriate methods be split up into pieces, each belonging to and surrounding a cell, or group of cells, and often disposed in concentric layers.

Close to the perichondrial surface of the cartilage the cells become smaller and separated by less intercellular

substance, until at length the transparent chondrigenous material is replaced by the fibrous collagenous substance of connective tissue (§ 22), and the cartilage cells take on the form of "connective tissue corpuscles."

21. In a very young embryo we find in the place of a sterno-costal cartilage nothing but a mass of closely-applied, undifferentiated, nucleated cells, having the same essential characters as colourless blood-corpuscles, or as the deepest epidermic cells. The rudiment, or embryonic model of the future cartilage thus constituted, increases in size by the growth and division of the cells. But, after a time, the characteristic intercellular substance appears, at first in small quantity, between the central cells of the mass, and a delicate sterno-costal cartilage is thus formed. This is converted into the full-grown cartilage (*a*) by the continual division and subsequent growth to full size, of all its cells, and especially of those which lie at the surface; (*b*) by the constant increase in the quantity of intercellular substance, especially in the case of the deeper part of the cartilage.

The manner in which this intercellular substance is increased is not certainly made out. If the outermost layer only of each of the protoplasmic bodies of adjacent cells of the epidermis were to become cornified and fused together into one mass, while the remainder of each cell continued to grow and divide and its progeny threw off fresh outer cornified layers, we should have an epidermic structure which would resemble cartilage except that the "intercellular substance" would be corneous and not chondrigenous. And it is possible that the intercellular substance of cartilage may be formed in this way. But it is possible that the chondrigenous material may be, as it were, secreted by and thrown out between the cells, as the constituents of the bile are thrown out between the hepatic cells, or at all events manufactured in some way by the agency of the cells, without the substance of the cells being actually transformed into it. Our knowledge will not at present permit us to form a definite judgment on this point. One thing, however, seems certain, viz. that the cells are in some way concerned in the matter; the matrix is unable to increase itself in the entire absence of cells.

The embryonic cells, which give rise to cartilage, are not distinguishable by any means we at present possess in any respect of importance from those which give rise to epidermis.

Nevertheless, the common form must disguise a different molecular machinery, inasmuch as the two, when set going by the conditions of temperature, supply of oxygen and nutriment to which they are exposed in the living economy, work out, as their ultimate products, tissues which differ so widely as cartilage and epidermis.

The embryonic cartilage cells, like the embryonic epidermic cells, are living organisms in which certain definitely limited possibilities of growth and metamorphosis are inherent, as they are in those equally simple organisms, the spores of the common moulds, *Penicillium* and *Mucor*. Given the proper external conditions, the latter grow into moulds of two different kinds, while the former grow into cartilage and horny plates.

22. *Connective Tissue* (see Lesson I. § 12).—A specimen of this tissue, taken from the deep surface of the integument or from between the muscles of a limb, is a soft stringy substance, which, if a small portion is carefully spread out in fluid on a glass slide and examined without the aid of any microscope, is seen to consist of semi-transparent whitish bands and fibres, of very various thicknesses, interlaced so as to form a network, the meshes of which are extremely irregular. Hence the older anatomists termed this tissue *areolar* or *cellular*.

Boiled in water, the connective tissue swells up and yields gelatine, which sets into a jelly as the water cools. After prolonged boiling, especially under pressure it almost entirely dissolves away into gelatine, only a small filamentous solid residue remaining behind.

Dilute acids and dilute alkalies also cause connective tissue to swell up and acquire a glassy transparency, but they do not dissolve it. For if to a portion of the tissue thus altered by either acid or alkali, alkali or acid is added sufficient to neutralise the first, the tissue returns to its normal condition.

If a specimen thus rendered transparent by dilute acetic acid is examined with a magnifying glass, fine dark lines and dots are seen to be scattered through

the apparently homogeneous substance. Placed under the microscope, the lines are seen to be sharply defined fibres of a strongly refracting substance. They are very elastic and are unaffected by even strong acids or alkalies or by prolonged boiling. Hence these *elastic fibres* formed a considerable part of the residue above mentioned.

The dots seen with the magnifying glass are shown by the microscope to be small nucleated cells. They are termed *connective tissue corpuscles*, just as cartilage cells are called *cartilage corpuscles.*

Thus, connective tissue resembles cartilage in so far as it consists of cells separated by a large quantity of intercellular substance; but this intercellular substance is soft, areolated, fibrous, and, for the most part, either collagenous or elastic, in contradistinction from that of cartilage, which is hard, solid, laminated and chondrigenous.

A specimen of fresh connective tissue prepared for the microscope in its own fluid exhibits a very different appearance. The field of view is occupied by strings or threads of extremely various thicknesses which cross one another in all directions and are often wavy. Some of the threads can be recognised as elastic by their strongly refracting character, but the majority of them are pale and not darkly contoured. All the thicker threads and strings present a fine longitudinal striation as if they were bundles of extremely fine fibrillæ (Fig. 95A). At intervals such bundles are often encircled by rings of a more refractive substance, and fibres of the like character may be disposed spirally round the bundles.

When dilute acetic acid is added to the specimen, the pale threads and longitudinally striated strings swell up and the longitudinal striation disappears; hence it is that the specimen becomes so transparent (Fig. 95B). Moreover it is these striated threads and strings which are dissolved by boiling water, and yield gelatine. We may therefore speak of them as *collagenous* or gelatine-yielding fibres, by way of distinction from the fibres of *elastic* substance, which do not yield gelatine on boiling, and are of a different chemical nature.

By various modes of maceration the collagenous fibres may be resolved into filaments which answer to the space

between the striæ, and are of such extreme fineness that they may measure less than 1μ in diameter. It would appear therefore that the intercellular substance

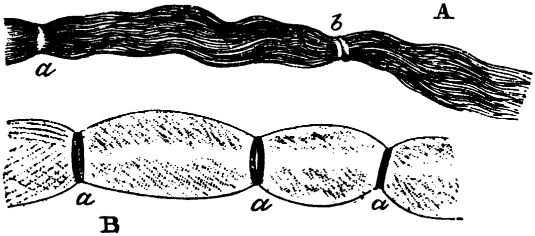

FIG. 95.

A. A small bundle of connective tissue, showing longitudinal fibrillation, and at *a* and *b* encircling (annular, spiral) fibres. Magnified 400 diameters.
B. A similar bundle swollen and rendered transparent by dilute acid. The encircling fibres are seen at *a*, *a*, *a*.

of the connective tissue in question, is composed of (*a*) *collagenous filaments*, united by some cementing substance into bundles, and of (*b*) *elastic* fibres. These latter are generally united into long meshed networks (Fig. 96).

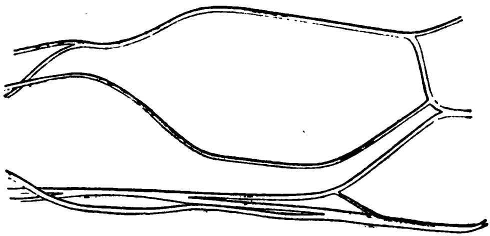

FIG. 96.—ELASTIC FIBRES OF CONNECTIVE TISSUE, FORMING A LOOSE NETWORK.

Obtained by special preparation from subcutaneous tissue. Magnified 800 diameters.

With care, the *cells* or *connective tissue corpuscles* also may be seen even in fresh, living connective tissue (Fig. 97); but, as has been stated, they are most distinctly visible

when the tissue is treated with dilute acetic acid. These cells, when seen in the fresh tissue, care being taken to prevent the post-mortem changes which they readily undergo, are found to be flattened plates almost like epithelial scales, but with very irregular contours. They closely adhere to, and are, as it were, bent round the convex faces of the larger bundles of collagenous fibres.

Besides these *fixed* connective tissue corpuscles as they are called, white blood corpuscles, or lymph corpuscles, or bodies exceedingly like them, are found lying loose in the fluid which occupies the meshes of the network of fibres, and appear to wander or travel through the spaces of the network by virtue of their power of amoeboid movement (Lesson III.). Such cells are spoken of as wandering or migratory cells.

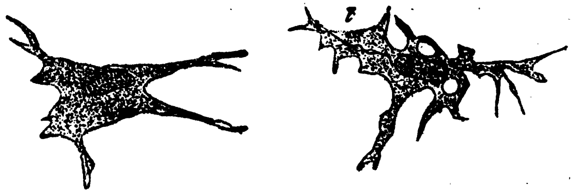

FIG. 97.—TWO CONNECTIVE TISSUE CORPUSCLES.
Each is seen to consist of a protoplasmic branched body, containing a nucleus. Very highly magnified.

23. Such are the characters of that which may be regarded as a typical specimen of connective tissue. But in different parts of the body this tissue presents great differences, all of which, however, are dependent upon the different relative extent to which the various elements of the tissue are developed.

Thus, (*a*) The intercellular substance may be very much reduced in amount in proportion to the cells, as is the case in the superficial layer of the derma and some other places.

(*b*) The intercellular substance is abundant, with the elastic elements well developed, and the collagenous elements, with fibrils strongly marked and arranged in close-set parallel bundles, leaving mere clefts in the place

of the wide meshes of ordinary connective tissue. This structure is seen in such dense and strong forms of connective tissue as ligaments and tendons.

(*c*) The elastic element predominates, as in the strong ligament (*ligamentum nuchæ*) which is so highly developed in long-necked animals, such as the horse, &c., and in the chordæ vocales of the larynx (see Lesson VII.).

(*d*) The fibrous or elastic elements abound, but a greater or less amount of chondrigenous substance is developed around the corpuscles. These are respectively the *fibro-cartilages* and *elastic cartilages*, which present every transition between ordinary cartilage and ordinary connective tissue (epiglottis, intervertebral ligaments). Where a tendon is inserted into a cartilage, as in the case of the tendo Achillis, the passage of the cartilage into the tendon is beautifully displayed. The intercellular substance of the cartilage gradually takes on the characters of that of the tendon, and the corpuscles of the cartilage become connective-tissue corpuscles.

(*e*) Finally, in many parts of the body fatty matter is found within the protoplasmic substance of the connective tissue corpuscles just as we have seen it to be formed in cartilage corpuscles. The fatty deposit increases in amount, at the same time distending the body of the cell, until the latter becomes a spheroidal sac full of fat, with the nucleus pushed to one side (Fig. 98). The conspicuous *fatty tissue* found in many parts of the body consists simply of an aggregation of vast numbers of these modified cells, held together by a vascular framework furnished by the connective tissue to which they belong.

24. In a young embryo, the places in which connective tissue will make its appearance are occupied by masses of simple undifferentiated nucleated cells. By degrees, the cells become separated from each other by a transparent intercellular substance or matrix, which eventually takes on the form of collagenous fibrils and elastic fibres, the relative proportion and the disposition of the two varying according to the kind of connective tissue which is being formed. As in the corresponding case of cartilage, the exact part played by the cells in the formation of this matrix is still a matter of dispute. As the development of the tissue proceeds, the cells multiply by

division and assume their characteristic flattened and irregular forms, applying themselves to or rather becoming compressed between the bundles of collagenous fibrils.

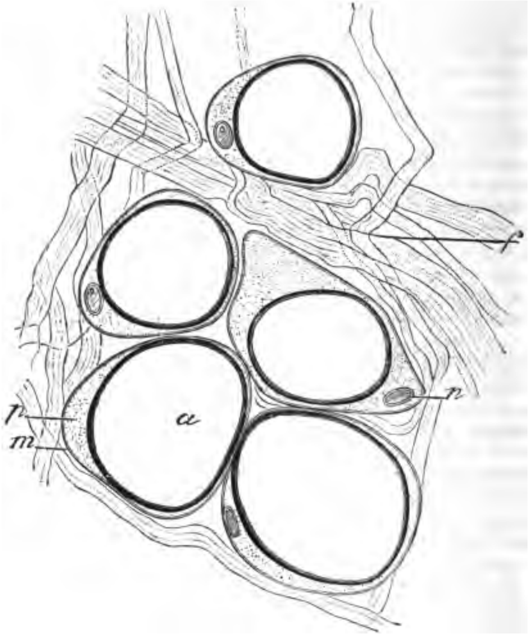

FIG. 98.—ADIPOSE TISSUE.

Five fat cells, held together by bundles of connective tissue *f*. *m*, the membrane or envelope of the fat cell; *n*, the nucleus, and *p*, the remains of the protoplasm pushed aside by the large oil drop *a*. Magnified 200 diameters.

25. *Osseous and dental tissues.*—The substances of which the bones and teeth are composed present very little apparent resemblance to cartilage and connective tissue, yet they are in reality very closely allied structures.

A fresh long bone, such as the femur or humerus of a

rabbit, from which the attached muscles, tendons and ligaments have been carefully cleaned away, but the surface of which has not been scraped or otherwise injured, is an excellent subject for the study of bone. It is a hard tough body which is flexible and highly elastic within narrow limits, but readily breaks, with a clean fracture, if it is pressed too far. The two articular ends are coated by a layer of cartilage which is thickest in the middle. Where the margins of the cartilage thin out a layer of vascular connective tissue commences, and extending over the whole shaft, to the surface of which it is closely adherent, constitutes the *periosteum*. If the bone is macerated for some time in water, the periosteum may be stripped off in shreds with the forceps. Filaments pass from its inner surface into the interior of the bone. If the shaft is broken across it will be found to contain a spacious *medullary cavity* filled by a reddish, highly vascular mass of connective tissue, abounding in fat cells, called the *medulla* or marrow; and a longitudinal section shows that this medullary cavity extends through the shaft, but in the articular ends becomes subdivided by bony partitions and breaks up into smaller cavities, like the areolae of connective tissue. These cavities are termed *cancelli*, and the ends of the bone are said to have a *cancellated* structure. The walls of the medullary cavity in the shaft are very dense, and exhibit no cancelli and appear at first to be solid throughout. But on examining them carefully with a magnifying glass it will be seen that they are traversed by a meshwork of narrow canals, varying in diameter from 20μ to 100μ or more. The long dimensions of the meshes lie parallel with the axis of the shaft. These are the *Haversian canals*. This system of Haversian canals opens by short communicating branches on the one hand upon the periosteal and on the other upon the medullary surface of the wall of the shaft; and in a fresh bone, minute vascular prolongations of the periosteum and of the medulla respectively, may be seen to pass into the communicating canals and become continuous with the likewise vascular contents of the Haversian canals. Moreover, at one part of the shaft there is a larger canal through which the vessels which supply the medulla pass. This is the so-called *nutritive foramen* of the bone. At

the two ends of the bone the cavities of the Haversian canals open into those of the cancelli; and the vascular substance which fills the latter thus further connects the vascular contents of the Haversian canals with the medulla.

Thus the bone may be regarded as composed of, *a*, an internal, thick, cylinder of vascular medulla; *b*, an external hollow, thin, cylindrical sheath of vascular periosteum, completed at each end by a plate of articular cartilage; *c*, of a fine, regular, long-meshed vascular network which connects the sides of the medullary cylinder with the periosteal sheath of the shaft; *d*, of a coarse, irregular vascular meshwork occupying at each end the space between the medullary cylinder and the plate of articular cartilage, and connected with the periosteum of the lateral parts of the articular end; *e*, of the hard, perfect osseous tissue which fills the meshes of these two networks. Such is the general structure of all long bones with cartilaginous ends, though some, as the ribs, possess no wide medullary cavity, but are simply cancellated in the interior. In some very small bones even the cancelli are wanting. And there are many bones which have no connection with cartilage at all.

26. If a bone is exposed to a red heat for some time in a closed vessel nothing remains but a mass of white "bone-earth," which has the general form of the bone, but is very brittle and easily reduced to powder. It consists almost entirely of calcic phosphate and carbonate. On the other hand, if the bone is digested in dilute hydrochloric acid for some time the calcareous salts are dissolved out, and a soft, flexible substance is left, which has the exact form of the bone, but is much lighter. If this is boiled for a long time it will yield much gelatin, and only a small residue will be left. Osseous tissue therefore consists essentially of an animal matter impregnated with calcic salts, the animal matter being collagenous like connective tissue, and not chondrigenous like cartilage.

27. A sufficiently thin longitudinal section made by grinding down part of the wall of the medullary cavity of a bone—which has been well macerated in water and then thoroughly dried—if viewed as a transparent

object with a magnifying glass, shows a series of lines, with dark enlargements at intervals, running parallel with the Haversian canals. If the section, instead of being longitudinal, were made transversely to the shaft, and therefore cutting through the majority of the Haversian canals at right angles to their length, similar lines and dark spots would be seen to form concentric circles at regular intervals round each Haversian canal (Fig. 99). The hard bony tissue appears therefore to be composed of lamellæ, which are disposed concentrically around the Haversian canals; and a Haversian canal with the concentric lamellæ belonging to it form what is called a Haversian system. The soft substance from which the bone-earth has been extracted is similarly lamellated, and here and there presents fibres which may be traced into the fibrous substance of the periosteum.

If a thin section of dry bone is examined with the microscope (Fig. 100), by transmitted light, each dark spot is seen to be a black body (of an average diameter of about 15μ) with an irregular jagged outline, and proceeding from it are numerous fine dark lines which ramify in the surrounding matrix and unite with similar branched lines from adjacent black bodies. The matrix itself has a somewhat granular aspect. In a transverse section these black bodies are rounded or oval in form, but in a longitudinal section they appear almost spindle-shaped; that is to say they are lenticular or lens-shaped, but flattened as it were between the adjacent layers of the matrix. Examined by reflected light the same bodies look white and glistening; and if the section instead of being examined dry, be boiled in water or soaked in strong alcohol, and brought under the microscope while still wet, the black bodies with their branching lines will be found to have almost disappeared, only faint outlines of them being left. At the same time minute bubbles of air will have escaped from the section. The black bodies seen in the dry bone are in fact "*lacunæ*," *i.e.* gaps, or holes in the solid matrix, appearing black by transmitted light and white by reflected light, because they are filled with air; and the dark branched lines are similarly, minute canals, "*canaliculi*," also filled with air-bubbles, drawn out so to speak into lines, also hollowed out of the solid matrix, and

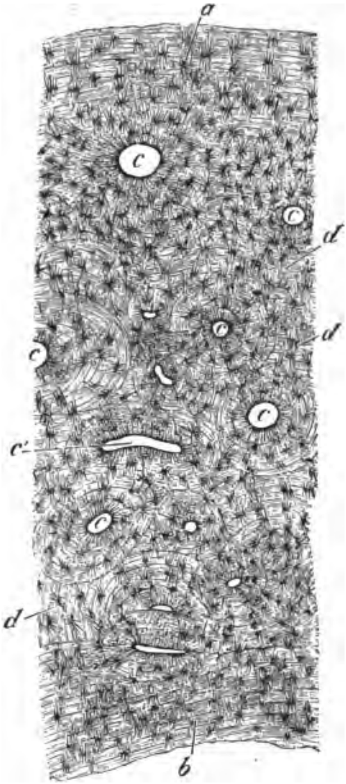

FIG. 99.—TRANSVERSE SECTION OF COMPACT BONE.

a, lamellae concentric with the external surface; *b*, lamellae concentric with the medullary surface; *c*, section of Haversian canals; *c'*, section of a Haversian canal just dividing into two; *d*, intersystemic lamellae. Low magnifying power.

placing one lacuna in communication with another. In each Haversian system the *canaliculi* and the *lacunæ* of

the innermost layer or that nearest the Haversian canal communicate with it, while the *canaliculi* and the *lacunæ* of the outermost layer communicate only with those of the next inner layer. Hence the *lacunæ* and *canaliculi* compose a meshwork of canals, which is peculiar to each Haversian system, and by which the nutritive plasm

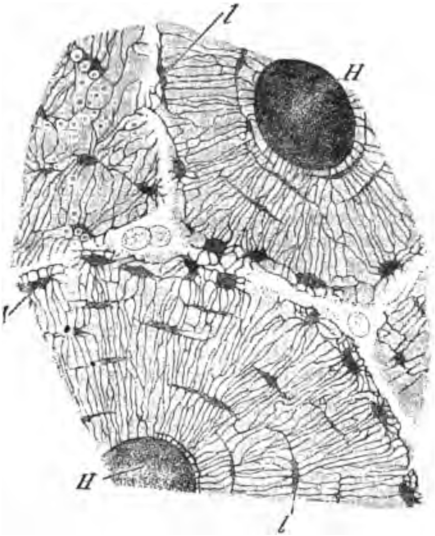

FIG 100.—TRANSVERSE SECTION OF BONE, HIGHLY MAGNIFIED (300 DIAMETERS).

H Haversian canals; *l*, lacunæ with canaliculi.

exuded from the vessels in the canal of that system irrigates all the layers of bone which belong to the system.

A very thin section of perfectly fresh bone exhibits no dark bodies, inasmuch as the lacunæ and canaliculi contain no air, but are permeated with the nutritive fluid. Each lacuna moreover, at all events in young bone,

contains a nucleated cell, which is altogether similar in essential character to a connective tissue or cartilage corpuscle, and if the term were not already misused might be called a "bone corpuscle." In fact, in ultimate analysis the essential character of bone shows itself to be this: that it is a tissue analogous to cartilage and connective tissue in so far as it consists of cells separated by much intercellular substance; and that it differs from them mainly in the fact that calcareous matter is deposited in and associated with the intercellular substance in such a way as to leave minute uncalcified passages (the *canaliculi*), which open into the larger uncalcified intervals (the *lacunæ*), in the neighbourhood of the cells.

The function of these passages is doubtless to allow of a more thorough permeation of the calcified tissue by the nutritive fluids than could take place if the calcareous deposit were continuous, and it is probable that, in an ordinary bone, there is no particle 1μ square which is not thus brought within reach of a minute streamlet of nutritive plasma.

28. This circumstance enables us to understand that which one would hardly suspect from the appearance of a bone, namely, that, throughout life, or, at all events, in early life, its tissue is the seat of an extremely active vital process. The permanence and apparent passivity of the bone are merely the algebraical summation of the contrary processes of destruction and reproduction which are going on in it.

If a young pig is fed with madder, its bones will be found after a time to be dyed red. The madder dye, in fact, getting into the blood, permanently dyes the tissue with which it meets in its course through the bones. But if the pig is fed for a time with madder, and is then deprived of it, the amount of colour to be found in the bones depends on the time which elapses before the pig is killed. And it is not that the colouring matter is merely, as it were, washed out; the dye is permanent, but the bones nevertheless become parti-coloured. In the shaft of a long bone, for instance, a certain time after feeding with madder, a deep red layer of bone in the middle of the thickness of its wall will be found to have colourless bone on its medullary and on its periosteal

face. And the longer the time which has elapsed since the feeding with madder, the more completely will the deep red bone be replaced and covered up by colourless bone.

Besides, careful inspection of a transverse section of the wall of the shaft of a long bone is by itself sufficient to show that bone is constantly being formed and as constantly removed. Such a section exhibits, as has been said, a number of Haversian canals surrounded by circular zones formed of concentric layers of bone. But interspersed between these there lie larger and smaller segments of zones formed of similar concentrically curved parallel lamellæ, the so-called intersystemic lamellæ (Fig. 99, *d*), which have evidently at one time formed parts of complete Haversian systems, but which have been partially destroyed and replaced by new systems. In fact, the formation of new bone is constantly taking place: *a*, at the surface in contact with the periosteum; *b*, at the surface in contact with cartilage; *c*, at the surface in contact with the medulla and its prolongations in the cancelli and Haversian canals; and the bone thus formed is after a time destroyed and replaced by new growths.

29. To understand this we must study the origin of osseous tissue. At a certain period of embryonic life there is no bone in any part of the body. Nevertheless, the greater number of the "bones," for example the vertebræ, the ribs, the limb bones, and some of the cranial and facial bones, exist in a morphological sense, inasmuch that cartilages having the general form of such bones exist in the places of the future bones. In the place of the humerus and the femur, for example, there are rods of pure cartilage, which are, so to speak, small rough models of the humerus and femur of the adult. When the process of bone formation commences slight opaque spots, termed "*centres of ossification*," make their appearance in the substance of the cartilage, the opacity being due to the deposit of calcareous salts at these points.

Microscopic examination shows that the calcareous salts are deposited in the intercellular substance, which, therefore, is converted into a sort of bone in which the

lacunæ are represented by the cavities of the cartilage corpuscles. These calcareous salts must reach the centres of ossification dissolved in the plasma which is exuded from the perichondrial vessels and permeates the intercellular substance.

In the cartilaginous rudiment of a long bone three such centres of ossification usually make their appearance, one in the centre of the shaft and one in each end. Supposing these centres to be formed at the same time (which may not however be the case), what we have to start from is a rudiment or model in cartilage of the future bone converted at three points into calcified cartilage; that is to say there is a central nodule (*diaphysis*) and two terminal nodules (*epiphyses*). If the deposit were to spread from three centres until the three nodules united the result would be a calcified cartilage in place of the formative cartilage.

As a matter of fact the deposit does spread through the rudiment from each centre outwards so long as the bone is growing. But the cartilage between the diaphysis and epiphyses and that beyond the ends of the epiphyses also grow and increase with the general growth of the bone. That beyond the epiphysial ossification remains throughout life as articular cartilage, while that between the epiphysial and diaphysial ossifications is gradually encroached upon by these and finally obliterated.

If this were all, the adult bone would consist of calcified cartilage tipped at the ends with cartilage which remained uncalcified. But this is not all; such a mass of calcified cartilage is not a true bone. The adult femur *e.g.* consists, not of calcified cartilage, but of true osseous tissue with the characters described above, there being no simple calcified cartilage anywhere except at the junction of the articular cartilages with the subjacent bone. And the true osseous tissue of the femur has a different origin from that just described, inasmuch as it has been produced by the calcification in a special way of a peculiar non-cartilaginous tissue developed from the vascular sheath of connective tissue surrounding the original cartilage, which is at first called perichondrium, but which, as ossification goes on, receives the name of periosteum. This perichondrial or periosteal tissue in a

somewhat complex manner destroys or absorbs the calcified cartilage and replaces it by true bone.

In fact, very soon after the ossific centres have made their appearance, vascular processes of the perichondrium grow into them. These processes make room for themselves by, in some way, causing the destruction and absorption of the calcified cartilage, giving rise to large irregular spaces or areolæ, which they occupy. The processes consist of blood-vessels surrounded by a peculiar form of connective tissue, characterized by the presence of large nucleated cells called *osteoplasts*. The perichondrium or periosteum from which these processes grow out has a similar structure and is also rich in osteoplasts.

No sooner have these processes hollowed out the areolæ in the calcified cartilage than they begin to line them with layers of true bone, the matrix of the connective tissue of the processes being calcified in such a way as to leave spaces in which some of the cells or osteoplasts remain imbedded, fine branching canals being left in the matrix, or being subsequently formed in it. In other words, layers of true bone, with lacunæ containing nucleated cells and with branched canaliculi, are thus constructed as a lining to the spaces hollowed out of the calcified cartilage. None of the spaces, however, are completely filled up, and there are no signs of regular Haversian systems with canals and concentric laminæ. The calcified cartilage is simply replaced by a loose open network of spongy bone, in the thickness of the bars of which may be seen the remains of the calcified cartilage, and the cavities of which are filled with blood-vessels and delicate connective tissue, that is, with marrow.

Meanwhile the perichondrium or periosteum, in addition to sending in these processes which thus convert the calcified cartilage into spongy but true bone, deposits layers of somewhat denser but still spongy bone, on the outside of the changed and changing ossific centre, in the form of a cylinder which grows in thickness by the addition of new layers on its surface, immediately under the periosteum, and in length by the extension of these cylindrical layers upwards and downwards. The "periosteal" bone, as this is called, is true bone, the deposition

of calcic salts taking place in the matrix around the osteoplasts in such a way as to leave lacunæ and canaliculi.

Very soon after this sheath of periosteal bone has made its appearance, the spongy bone first formed in the calcified cartilage is absorbed again by the same vascular

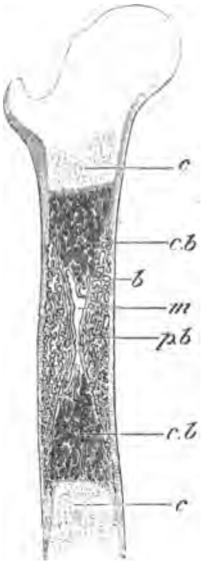

FIG. 101.—LONGITUDINAL SECTION OF OSSIFYING HUMERUS (DOG).
c, the original primitive cartilage; *c*, *b*, spongy bone arising from ossification of cartilage; this has already been absorbed and replaced by medulla at *m*; *p b*, bone (also spongy) formed by the periosteum; it is seen extending as a thin sheet upwards and downwards outside the cartilage. (Magnified 7 diameters.)

processes which formed it, so that soon what was at first the centre of ossification, after passing from simple cartilage to calcified cartilage, and so to spongy bone, is resolved into marrow or medulla, that is into vascular connective tissue richly loaded with fat.

Thus, confining our attention to the diaphysis, we may say that the primitive femur becomes cut into two halves by the substitution of vascular medulla for the primitively non-vascular cartilage. But the cartilage of each half continues to grow in length and thickness nearest the medulla, and to be successively converted first into

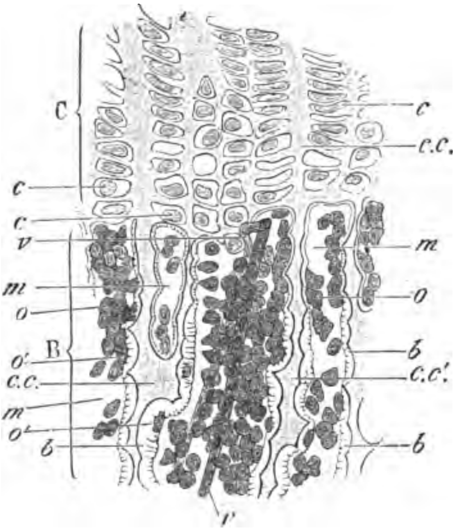

FIG. 102.—LONGITUDINAL SECTION OF OSSIFYING CARTILAGE.
C, region of cartilage; *B*, region of bone.
In *C* are seen the cartilage cells, *c*, lying in their cavities, and, arranged in columns between them, are the bars of calcified matrix *c c*.
In *B* are seen the long irregular medullary spaces *m*, containing the osteoplasts *o*, and in one is seen a blood-vessel *v*. These spaces are becoming lined with true bone, *b*, in which, as at *o'*, the osteoplasts are entangled, and the canaliculi visible. At *c c'* are seen the remains of the calcified cartilage, coated with true bone on each side.

calcified cartilage and then into spongy bone at its end nearest the medulla.

The two halves, however, are held together by the ring or cylinder of periosteal bone just described, which grows

in thickness and length as the primitive cartilage of the two halves become more and more separated by calcified cartilage, spongy bone and medulla. The medulla increases rapidly until the diaphysis assumes the form of a cylinder of periosteal bone, with narrow but thicker walls in the middle, and with wider but thinner walls at each end, somewhat like a long narrow dice-box (Fig. 101). The middle of the cylinder is occupied by medulla alone, but each end is, as it were, plugged by a disc of cartilage undergoing conversion into calcified cartilage, then into spongy bone, and finally into medulla.

If we take a vertical section of one of these discs (Fig. 102), we may trace out these changes as they are taking place.

In the vicinity of its outer face the cartilage cells are undergoing rapid multiplication, and arrange themselves in columns parallel with the long axis of the bone, and therefore perpendicular to the face of the zone of calcified cartilage. Between these columns the calcified intercellular substance forms partitions, so that the columnar masses of cells lie in deep honeycomb-like chambers with calcified walls.

Lower down these chambers are seen to be broken into by vascular processes of the medulla, and converted into larger irregular chambers, the walls of which are being lined wtih true bone, containing lacunæ and canaliculi. Still lower down the walls of these new chambers are seen to be again absorbed, until nothing is left but medulla.

As the developing bone grows the discs get farther and farther apart, and the medulla grows longer until the two ends of the diaphysis meet the epiphyses, and unite with them. The whole disc thus becomes at last spongy bone continuous with the similar spongy bone into which the epiphysis is converted, all that remains of the calcified cartilage being an exceedingly thin layer just below the articular cartilage at either end of the bone.

Thus though the primitive cartilage serves as the model of the future bone, a great deal of the bone, namely, the dense compact bone which forms the shaft and is continued as a shell over the two ends, does not come from the cartilage at all but is deposited by the periosteum ;

the spongy bone at each end is the only part that is formed in the cartilage, and even in that as we have seen there are no remains of the cartilage itself.

Moreover the bone even thus formed is subject to incessant change. The periosteal bone is at first spongy and slight in texture, and exhibits no true Haversian systems. Little by little spaces are scooped out in it by vascular processes of the periosteum on the outside and of the medulla on the inside, like those which formed it; and such a space when formed is in turn filled up in a solid fashion by layers of bone deposited in a regular way as concentric lamellæ round the blood-vessel of the process, which in the end remains as the blood-vessel of the Haversian canal, in the centre of the Haversian system thus deposited. And indeed similar processes of absorption and fresh formation go on certainly while the bone is increasing in size, and probably also for some time afterwards.

A good many bones, such as the frontal and parietal bones of the skull, have no cartilaginous precursors. The roof of the skull of an embryo is formed of connective tissue, and the primitive centre of ossification in which one of the bones commences is a calcification of that part of the connective tissue which occupies the place of the centre of the future bone. The calcification radiates from this centre outwards, so that it soon has the form of a thin plate, the margins of which are as it were frayed out in filaments. The vascular connective tissue which incloses the plate becomes its periosteum, and plays the same part in relation to the growing bone as the periosteum of cartilage bone does to it. As the plate grows thicker, medullary processes burrow into it and give rise to cancelli and Haversian systems.

30. *Dental tissues.*—The general characters of the teeth have been given in Lesson VI. § 15. Each tooth presents a *crown*, which is visible in the cavity of the mouth, where it becomes worn by attrition with the tooth opposite to it and with the food; and one or more *fangs*, which are buried in a socket furnished by the jawbone and the derma of the dense mucous membrane of the mouth, which constitutes the *gum*. The line of junction between the crown and the fang is the *neck* of the tooth. In the interior of the

tooth is a cavity communicating with the exterior by canals, which traverse the fangs and open at their points. This cavity is the *pulp cavity*. It is occupied and completely filled by a highly vascular tissue richly supplied with nerves, the *dental pulp*, which is continuous below, through the openings of the fangs, with the vascular derma of the gum which lies between the fangs and the alveolar walls, and plays the part of periosteum to both.

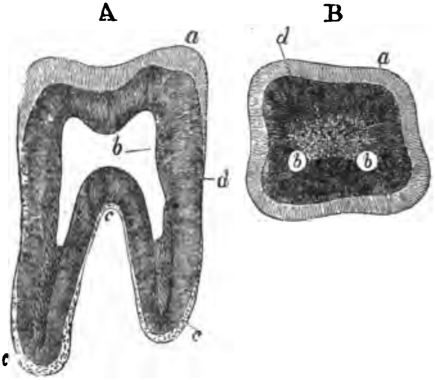

FIG. 103.
A, vertical, B, horizontal section of a tooth.—*a*, enamel of the crown; *b*, pulp cavity; *c*, cement of the fangs; *d*, dentine. (Magnified about three diameters.)

31. The tissue which forms the chief constituent of a tooth is termed *dentine* (Fig. 103, A, B, *d*). It is a dense calcified substance containing less animal matter than bone, and further differing from it in possessing no lacunæ, or proper canaliculi. Instead of these it presents innumerable, minute, parallel, wavy tubules (Fig. 104 *d*), which give off lateral branches. The wider inner ends of these tubules may measure 4μ or 5μ; they open into the pulp cavity, while the narrower outer terminations ramify at the surface of the dentine, and may even extend into the enamel or cement (Fig. 104).

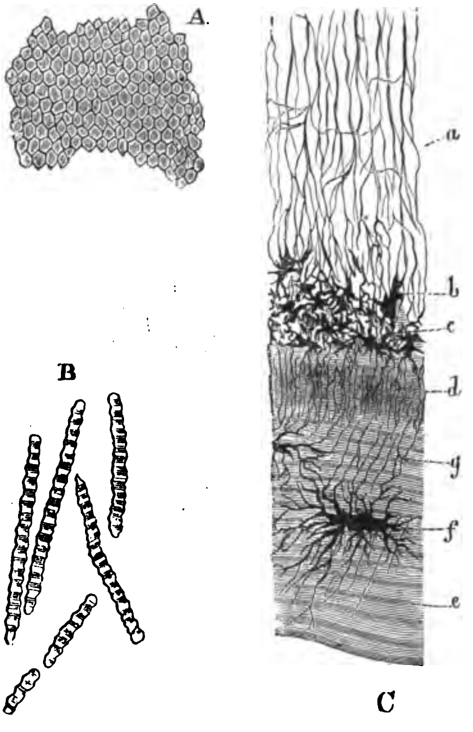

FIG. 104.
A. Enamel fibres viewed in transverse section.
B. Enamel fibres separated and viewed laterally.
C. A section of a tooth at the junction of the dentine (*a*) with the cement (*e*); *b*, *c*, irregular cavities in which the tubules of the dentine end; *d*, fine tubules continued from them; *f*, *g*, lacunæ and canaliculi of the cement. (Magnified about 400 diameters.)

The greater part of the crown and almost the whole of the fangs consist of dentine. But the summit of the crown

is invested by a thick layer of a much denser tissue, which contains only 2 per cent. of animal matter, and is almost of a stony hardness. This is called *enamel* (Fig. 103, A, B, *a*). It becomes thinner on the sides of the crown and gradually dies out on the neck. Examined microscopically, the enamel is seen to consist of six-sided prismatic fibres (Fig. 104, A. B.) set closely side by side, nearly at right angles to the surface of the dentine. These fibres measure not more than 3μ to 5μ in transverse diameter and present transverse striations.

The third tissue found in teeth is a thin layer of true bone, generally devoid of Haversian canals, which invests the outer surface of the fangs and thins out on the neck. This is termed *cement* (Fig. 103, A, *c*; and Fig. 104, C).

The dental pulp is chiefly composed of delicate connective tissue. It is abundantly supplied with vessels and nerves, which enter it through the small opening at the extremity of the fang. The nerves are mainly sensory branches derived from the fifth pair of cranial nerves.

The superficial part of the pulp, which is everywhere in immediate contact with the inner surface of the dentine, consists of a layer of nucleated cells so close set that they almost resemble an epithelium. They are, however, in reality connective-tissue cells, and the layer is merely a slightly modified condition of the stratum of undifferentiated connective tissue, which lies at the surface of every dermic structure. They are comparable with the osteoplasts of growing bone, and from them long filamentous processes can be traced into the dentinal tubules.

32. The teeth begin to be developed long before birth, and while the jaw bones are in a very rudimentary condition. The deep face of the epithelium covering the free surface of the gum thickens into a ridge, and thus depresses the corresponding face of the derma, which at the same time grows up at the sides of the ridge. In this way a semicircular groove, which is termed the *dental groove*, is developed in the derma of the gum of each jaw. But it must be remembered that the epithelium completely fills the groove and passes from side to side smoothly over it. Next, each groove, that in the upper jaw and that in the lower, becomes subdivided into ten pouches, five on each side of the middle line, and behind

the fifth on each side there remains a residue of the groove, which may be called a *residual pouch.*

Each of the first-mentioned pouches becomes gradually more and more distinct from its neighbours, until at length its walls unite and shut off the epithelium which it contains from the cavity of the mouth. The result is a closed bag full of epithelium, which is a milk *tooth sac.* At the same time the derma of the bottom of the sac has grown up as a conical process into its interior; and this *dental papilla* is the rudiment of the future tooth. It follows that the epithelium of the sac now forms a thick cap, the convexity of which is applied to the walls of the sac, while its concavity fits accurately on the surface of the papilla.

While the milk-tooth sac is thus shaping itself, its epithelium grows out on one side into a small process, which gradually increases in size and takes on the characters of a second tooth sac. This is the sac of the *permanent* tooth, which answers to and will replace each milk tooth.

A similar change takes place in the residual pouches, each of which gradually becomes divided into three sacs for the three hindmost permanent teeth in each jaw.

The sacs of the milk teeth rapidly increase in size and become separated from one another by partitions of bone developed from the jaw with which they are in relation, and which grow up round them. They thus become lodged in alveoli.

The papilla becomes vascular, and in its central part, the cells of which it is primitively composed give rise to connective tissue. At its surface it retains its embryonic characters, except that the cells become slightly elongated perpendicularly to the surface. These cells, which are termed *odontoplasts*, are separated by a delicate structureless basement membrane from the very similar cells of the epithelial cap. This is now termed the *enamel organ.* It consists of (*a*) a layer of somewhat elongated close-set cells adherent to basement membrane covering the papilla, the *papillary epithelium*; (*b*) of a layer of less elongated close-set cells, adherent to the walls of the sac, the *parietal epithelium*, continuous with the papillary epithelium at the base of the papilla;

(*c*) of *intermediate cells* which have a more or less stellate form, and adhere loosely.

The proper tooth substance first makes its appearance as a very thin hollow cap of glassy calcareous deposit at the summit of the papilla, between the layer of odontoplasts and the papillary epithelium. This cap gradually extends over the whole surface of the papilla (which has in the meanwhile taken on the form of the future tooth), and increases in thickness from the summit towards the base, so that the part of the tooth which is first formed remains, and the new tooth substance can be added only to its papillary face and to its basal margins. Hence, the increase of the tooth is accompanied by decrease of the papilla, which eventually remains in the cavity of the finished tooth as the pulp. In the region of the crown, the calcareous deposit which first takes place is extremely dense, and takes on a prismatic structure; but in the deeper layers the deposit takes place in such a manner as to leave fine interspaces, which become the dentinal canals. The substance of the pulp has exactly the same relation to the dentinal canals as the substance of ossifying periosteal or medullary tissue has to the canaliculi, and a layer of the odontoplasts remains as the layer of cells mentioned in § 31 as forming the superficial part of the pulp. The pulp cavity is, as it were, a gigantic lacuna containing myriads of cells instead of one.

There can be no doubt about the mode of origin of dentine. But it should be stated that in the opinion of many the enamel fibres result, not as described above, from a calcification of the papilla, but from a calcification of the cells of the papillary epithelium.

33. The fully formed milk teeth press upon the upper walls of the sacs in which they are inclosed, and, causing a more or less complete absorption of these walls, force their way through. The teeth are then, as it is called, *cut*.

The cutting of this first set of teeth, called *deciduous*, or *milk teeth*, commences at about six months, and ends with the second year. They are altogether twenty in number—eight being cutting teeth, or *incisors;* four, eye teeth, or *canines;* and eight, grinders, or *molars*.

It has been seen that each dental sac of the milk teeth,

as it is formed, gives off a little prolongation, which becomes lodged in the jaw below the milk tooth, enlarges, and develops a papilla from which a new tooth is formed. As the latter increases in size, it presses upon the root of the milk tooth which preceded it, and thereby causes the absorption of the root and the final falling out, or shedding, of the milk tooth, whose place it takes. Thus every milk tooth is replaced by a tooth of what is termed the *permanent dentition*. The permanent *incisors* and *canines* are larger than the milk teeth of the same name, but otherwise differ little from them. The permanent teeth, which replace the milk molars, are small, and their crowns have only two points, whence they are called *bicuspid*. They never have more than two fangs.

We have thus accounted for twenty of the teeth of the adult. But there are thirty-two teeth in the complete adult dentition, twelve grinders being added to the twenty teeth which correspond with, and replace, those of the milk set. Permanent back grinders, or *molars*, are developed in the sacs which are formed out of the residual pouches above mentioned. They have four or five points upon their square crowns, and, in the upper jaw, commonly possess three fangs.

The first of these teeth, the anterior molar of each side, is the earliest cut of all the permanent set, and appears at six years of age. The last, or hindermost, molar is the last of all to be cut, usually not appearing till twenty-one or twenty-two years of age. Hence it goes by the name of the "wisdom tooth."

34. *Muscle* (*striated*).—It is necessary to distinguish "muscle" as an organ from "muscle" as a tissue.

The biceps muscle, for example (Lesson VII. § 6), is an organ of a complicated character, of which muscular tissue forms the predominant constituent only.

As an organ it presents as separate constituents in it, *a*, a muscle case or *perimysium*; this is a sheath of connective tissue from the inner face of which partitions proceed and divide the space which it incloses into a great number of longitudinally disposed compartments; *b*, the muscular fibres which occupy these compartments; *c*, the vessels which lie in the sheath and in the partitions between the compartments, and thus surround the mus-

cular fibres without entering them; *d*, the motor nerves which also at first lie in the sheath and in the partitions between the compartments, but which eventually enter into the muscular fibres.

The *perimysium* forms a complete envelope around the muscle, which, when it is sufficiently strong to be dissected off, is known as a *fascia;* at each end it usually terminates in dense connective tissue (*tendon*), which becomes continuous with the bone or cartilage to which the tendon is attached. The partitions given off from the inner surface of the perimysium form at first coarse compartments, inclosing large bundles, each consisting of a very great number of fibres. These large bundles are again divided by somewhat finer connective tissue partitions into smaller bundles, and these again into still smaller ones, and so on, the smallest bundles of all being composed of a number of individual muscular fibres. In this way the partitions become thinner and more delicate, until those which separate the chambers in which the individual muscular fibres are contained are reduced to little more than as much connective tissue as will hold the small nerves, arteries and veins and capillary networks together. As the perimysium consists of connective tissue, it may be destroyed by prolonged boiling in water. In fact, in "meat boiled to rags" we have muscles which have been thus treated; the perimysial case is broken up, and the muscular fibres, but little attacked by boiling water, are readily separated from one another.

If a piece of muscle of a rabbit which has been thus boiled for many hours, is placed in a watch-glass with a little water, the muscular fibres may be easily teased out with needles and isolated. Such a fibre will be found to have a thickness of somewhere about 60μ (they vary, however, a great deal), with a length of 30 or 40 millimetres, *i.e.* about 1½ inch. It is a cylindroidal or polygonal solid rod, which either tapers or is bevelled off at each end. By these it adheres to those on each side of it; or, if it lies at the end of a series, to the tendon.

The structure and properties of striated muscular tissue in the histological sense means the structure and properties of these fibres.

35. The general physical and chemical characters of muscle and its more conspicuous vital properties have been already dealt with (Lesson VII. § 4), so that it remains only to speak of those characters which are revealed by microscopic investigation.

As we have already had occasion to remark, all tissues undergo considerable alteration in passing from the living to the dead state, but, in the case of muscle, the changes

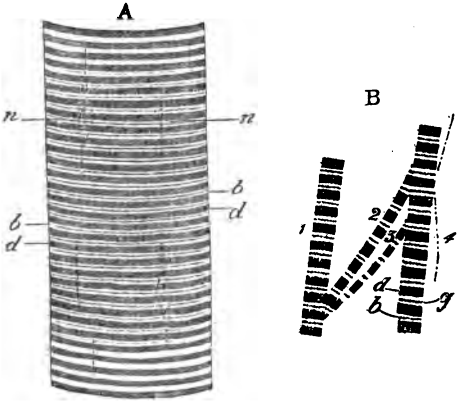

FIG. 105.

A. Part of a muscular fibre (of a frog) seen in a natural condition. *d*, dim bands; *b*, bright bands, with the granular line seen in many of them; *n*, nuclei and the granular protoplasm belonging to them, very dimly seen.
B. Portion of prepared mammalian muscular fibre teased out, showing longitudinal portions of variable (1. 2. 3. 4.) thickness; 4 represents the finest portion (fibrilla) which could be obtained; *d*, dark bands; *b*, bright bands, in the midst of each of which is seen the granular line *g*.

which the tissue undergoes in dying, are of such a marked character that the structure of the dead tissue gives a false notion of that of the living tissue.

A living striated muscular fibre of a frog or a mammal is a pale transparent rod composed of a soft, flexible, elastic substance, the lateral contours of which, when the fibre is viewed out of the body, appear sharply defined, like those of a glass rod of the same size; but when

the fibre is observed in the living body, bathed in the lymph which surrounds it, the outlines are not so sharply defined. In neither case can any distinct line of demarcation between a superficial layer and a deeper substance be recognised. The fibre appears transversely striped, as if the clear glassy substance were, at regular intervals (Fig. 105, A. *d*), converted into ground glass, thus appearing dimmer. Each of these "dim bands" is about 2μ wide, and the clear space or "bright band" which separates every two dim bands is of about the same size, or under ordinary circumstances somewhat narrower. With a high power a very thin dark granular line equidistant from each dim band is discernible in each bright band, dividing the bright band into two. As these appearances remain when the object glass is focussed through the whole thickness of the fibre, it follows that the dim bands, the granular lines, and the clear spaces on each side of each granular line, represent the edges of segments of different optical characters, which regularly alternate through the whole length of the fibre. Let the excessively thin segments, of which the thin granular lines represent the edges, be called *g*, the thicker, pellucid segments of which the bright bands on each side of a granular line represent the edges, B; and the thickest slightly opaque segments of which the ground glass like dim bands are the edges, D. Then the structure of the fibre may be represented by *D. B. g. B. D. B. g. B.* indefinitely repeated, and one inch of length of fibre will contain about 30,000 such segments, or alternations of structure.

In a perfectly unaltered living fibre the striated substance presents hardly any sign of longitudinal striation; but near to the surface of the fibre in mammalian muscle, though at various points in the depth of the fibre in the muscles of the frog, faint indications are to be observed of the existence of cavities each filled by a nucleus, surrounded by a small amount of protoplasm (Fig. 105, A. *n*). These are the so-called *muscle corpuscles.*

As the muscular fibre dies it undergoes a rapid alteration:—*a*, parallel longitudinal striæ, often less than 2μ apart, appear in greater or less numbers until sometimes the striated substance appears broken up into a mass of fine delicate fibres; *b*, the dim bands become much more

opaque, and hence the transverse striation appears better marked, until the dim bands may appear like sharply defined discs ; *c*, the nuclei acquire sharp irregular contours and become much more conspicuous, and *c*, especially under certain circumstances and after particular treatment, a thin superficial layer becomes sharply separated from the deeper substance of the fibre as a membrane of glassy transparency, the *sarcolemma*, which ensheathes the striated and fibrillated substance.

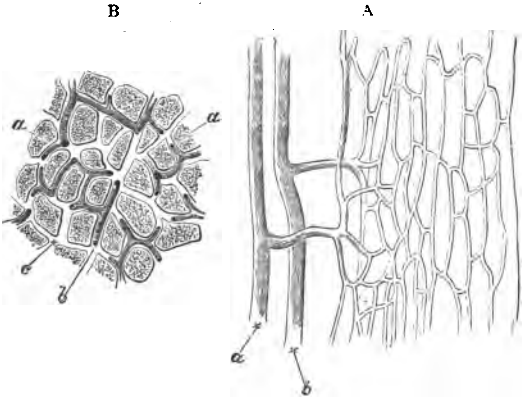

FIG. 106.—CAPILLARIES OF STRIATED MUSCLE.

A. Seen longitudinally. The width of the meshes corresponds to that of an ultimate fibre. *a*, small artery ; *b*, small vein.

B. Transverse section of striated muscle. *a*, the cut ends of the ultimate fibres ; *b*, capillaries filled with injection material ; *c*, parts where the capillaries are absent or not filled.

The bright bands and the granular lines, on the other hand, undergo little alteration.

Under very high powers each granular line looks like a number of minute granules coherent into an extremely attenuated plate, the margins of which are attached to the sarcolemma.

If the sarcolemma of a dead fibre be torn with needles, the striated substance breaks up in different ways according to the treatment to which the fibre has been

previously subjected. It may break up into discs, each of which contains a dim band. Or it may break up into fibrils, each of which presents the same segmentation as the whole fibre. These artificial fibrils vary much in thickness according to mode of preparation and the skill of the operator; they may sometimes be obtained of exceeding fineness (Fig. 105, B.). Transverse sections of muscular fibre, which have been frozen while perfectly fresh, present minute close-set circular dots, which appear to represent the transverse sections of naturally existing longitudinal fibrils. If the muscle substance is

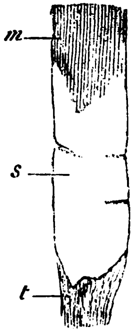

FIG. 107.—A MUSCULAR FIBRE (OF FROG) ENDING IN TENDON.
The striated muscular substance, *m*, has shrunk from the sarcolemma, *s*, the fibrils of the tendon, *t*, being attached to the latter.

really in this case unaltered the only possible interpretation of the fact is that the fibre is really made up of fibrils, and that these are invisible in the living muscle on account of their having the same refractive power as the interfibrillar substance. But whether the finest artificial fibrils into which dead muscle may be broken up are identical with these apparently natural fibrils, it is not at present certainly determined. In some cases the artificial fibrils seem smaller than the natural ones, as if the latter, like the fibre itself, were capable of longitudinal cleavage.

These are the most important structural appearances

presented by ordinary striated muscle. But it may further be noticed that the dim bands exert a powerful depolarising influence on polarised light. Hence when a piece of muscle is placed in the field of a polarising microscope and the prisms are crossed so that the field is dark, these bands appear bright. The granular lines have a similar but very much less marked effect.

36. As in the case of the preceding tissues so in that of muscle, the place of the adult tissue is occupied in the embryo by a mass of closely applied, undifferentiated nucleated cells. As development proceeds, some of these cells are converted into the tissues of the perimysium, but others increasing largely in size gradually elongate and take on the form of more or less spindle-shaped rods or fibres. Meanwhile the nucleus of each cell repeatedly divides, and thus each rod becomes provided with many nuclei, so that each fibre is really a multi-nucleate cell. Along with these changes the protoplasmic substance of the original cell becomes, for the most part, converted into the characteristically striated muscle substance, only a little remaining unaltered around each nucleus as a muscle corpuscle.

37. The many-nucleated cell metamorphosed into a muscular fibre is nourished by the fluid exuded from the adjacent capillaries, and it may be said to respire, insomuch as its substance undergoes slow oxidation at the expense of the oxygen contained in that fluid, and gives off carbonic acid. It is, in fact, like the other elements of the tissues, an organism of a peculiar kind, having its life in itself, but dependent for the permanent maintenance of that life upon the condition of being associated with other such elementary organisms, through the intermediation of which its temperature and its supply of nourishment are maintained.

The special property of a living muscular fibre, that which gives it its physiological importance, is its peculiar contractility. The body of a colourless blood corpuscle, as we have seen, is eminently contractile, insomuch as it undergoes incessant changes of form. But these changes take place at all points of its surface, and have no definite relation to the diameter of the corpuscle, while the contractility of the muscular fibre is manifested by a

diminution in the length and a corresponding increase in the thickness of the fibre. Moreover, under ordinary circumstances, the change of form is effected very rapidly, and only in consequence of the application of a stimulus.

When a contracting striated fibre is observed under the microscope all the bands become broader (across the fibre) and shorter (along the fibre) and thus more closely approximated. Some observers think that the clear bands are diminished in total bulk relatively to the dim bands; but this is disputed by others. When the fibre relaxes again the bands return to their previous condition.

38. *Non-striated muscle.*—This kind of muscle (also called plain or smooth muscle) which occurs in the walls of the alimentary canal, the blood-vessels, the bladder, and other organs, resembles striated muscle in being composed of fibres, which are bound together by connective tissue carrying blood-vessels and nerves; but the

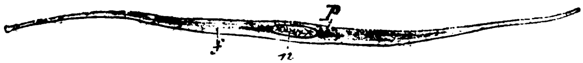

FIG. 108.—A FIBRE-CELL FROM THE PLAIN, NON-STRIATED MUSCULAR COAT OF THE INTESTINE.

p, granular protoplasm around the nucleus.

non-striated muscular fibre differs greatly from the striated fibre. It is very much smaller, being only about 6μ in width, and from 20μ to 50μ in length, and therefore cannot be seen by the unassisted eye, whereas a large unbroken striated fibre is visible to a sharp eye. It has only one nucleus, possesses no sarcolemma, and its substance is not transversely striated. It is, in fact, a cell which has become elongated into a flattened spindle, with an oval or sometimes rod-shaped nucleus in its middle (Fig. 108). A number of such fibre-cells are united together by a minute quantity of cement or intercellular substance into a thin flat band, and a number of such bands are bound together by connective tissue into larger bands or bundles. Each fibre is capable of contracting, of shortening into a thicker oval.

39. *Cardiac muscular tissue.*—The muscular tissue of the heart is intermediate in character between striated and non-striated muscle. Like the non-striated muscle, it is

composed of cells, each containing a single nucleus, and possessing no sarcolemma. But the cells (Fig. 109) are generally short and broad, frequently branched or irregular in shape, and their substance is more or less distinctly striated, like the substance of a striated fibre. A number of such cells are joined by cement substance into sets of anastomosing fibres, which are built up in a complex interwoven manner into the walls of the ventricles and auricles.

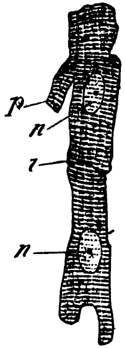

FIG. 109.—CARDIAC FIBRE CELLS.

Two cells isolated from the heart. *n*, nucleus; *l*, line of junction between the two cells; *p*, process joining a similar process of another cell. (Magnified 400 diameters.)

40. *Nervous tissue.*—The characters of nervous tissue are very different in different parts of the nervous system. We may best begin with the study of a motor nerve—such an one, for example, as that which supplies the biceps muscle.

Like the muscle, the nerve is a compound organ consisting of, (*a*,) a nerve-case or *perineurium* (formerly known as the *neurilemma*[1]), partitions from which inclose a great number of parallel tubular cavities, each of which contains, (*b*,) a *nerve fibre*.

The *perineurium*, like the perimysium, is composed of connective tissue and supports the scanty vessels of the

[1] See note, p. 356.

nerve. It consists of an external layer, which envelops the whole nerve, and, within this, layers disposed concentrically around, and thus forming secondary sheaths for, larger and smaller bundles of nerve fibres. Within these secondary sheaths smaller and smaller groups are formed until at length partitions, incomplete and of extreme tenuity, are formed between the individual nerve fibres.

41. The *nerve fibres*, which are the essential elements of the nerve, vary in diameter from 2μ to 12μ. In the living state they are very soft cylindrical rods of a glassy, rather strongly refracting aspect. No limiting membrane is distinguishable from the rest of the substance of the rod, but running through the centre of it a band of somewhat less transparency than the rest may be discerned. At intervals, the length of which varies, but is always many times greater than the thickness of the rod, the nerve fibre presents sharp constrictions, which are termed *nodes* (Fig. 110. B. *n n*). Somewhere in the interspace between every two nodes, very careful examination will reveal the existence of a nucleus (Fig. 110, B. *n c*), invested by more or less protoplasmic substance and lying in the substance of the rod, but close to the surface.

As the fibre dies, and especially if it is treated with certain re-agents, these appearances rapidly change. 1. The outermost layer of the fibre becomes recognisable as a definite membrane, the *neurilemma*[1] (the so-called "primitive sheath" or "sheath of Schwann"). 2. The central band becomes more opaque, and sometimes appears marked with fine longitudinal striæ as if it were composed of extremely fine fibrillæ; it is the *neuraxis* ("axis cylinder" or "axis fibre" of Remak). 3. Where the neuraxis traverses one of the nodes the neurilemma is seen to embrace it closely, but in the intervals between the nodes a curdy-looking matter, which looks white by reflected light, occupies the space between the *neuri-*

[1] This word was formerly used to denote the whole nerve-case, now called *perineurium*; but its similarity to the word *sarcolemma* led to great confusion in the minds of students. It is undoubtedly a wholesome rule never to use an old word in a new sense; but the striking similarity between the two words "neurilemma" and "sarcolemma," and between the nerve-fibre sheath and the muscle-fibre sheath, seems an adequate excuse for an exception to the rule.

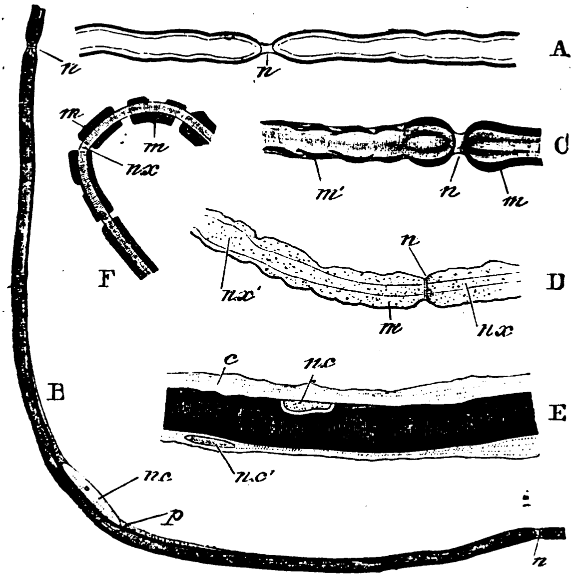

FIG. 110.—TO ILLUSTRATE THE STRUCTURE OF NERVE FIBRES.

A. A nerve fibre seen without the use of reagents, showing the "double contour" due to the medulla, and, *n*, a node. Neither neuraxis nor neurilemma can be distinctly seen. (Magnified about 300 diameters.)

B. A thin nerve fibre treated with osmic acid, showing, *nc*, nucleus with protoplasm, *p* surrounding it, beneath the neurilemma; *n n*, the two nodes marking out the segment to which the nucleus belongs. (Magnified 400 diameters.)

C. Portion of fibre (thicker than B), treated with osmic acid to show the node *n*; *m*, the densely stained medulla; at *m'* the medulla is seen divided into segments. (Magnified 350 diameters.)

D. Portion of nerve fibre treated to show the passage of the neuraxis, *n x*, through the node, *n*; *m*, the medulla. At *n x'* the neuraxis is swollen by the reagents employed and large and irregular. (Magnified 300 diameters.)

E. Portion of nerve fibre treated with osmic acid, showing the nucleus, *n c*, embedded in the medulla; *c*, fine perineurial sheath lying outside the neurilemma, the outline of the latter can only be recognised over the nucleus *n c.*; the nucleus, *n c'*, belongs to this perineurial sheath. (Magnified 400 diameters.)

F. Portion of nerve fibre deprived of its neurilemma and showing the medulla broken up into separate fragments, *m m*, surrounding the neuraxis, *n x*.

lemma and the *neuraxis*. This is the *medulla* (the so-called "white substance of Schwann") largely composed of a complex fatty substance, often spoken of as *myelin*. If the neurilemma of a fresh fibre is torn, the myelin flows out and forms irregular lumps as if it were viscous. The medulla is broken, by oblique lines (Fig. 110, C. *m*), extending from the neuraxis to the neurilemma, into segments, the faces of which are obliquely truncated and fit closely against one another. These may be seen even in quite fresh and living nerve fibres. 4. The internodal nucleus is more sharply defined; and it will be seen to be attached to the inner surface of the neurilemma.

The motor nerve, proceeding to its muscle, enters the perimysium (with which the superficial layer of the perineurium becomes continuous), and divides in the perimysial septa into smaller and smaller branches, each of which contains the continuation of a certain number of the fibres of the nerve trunk, bound up into a bundle by themselves. In these larger ramifications of the nerve trunk there is no branching of the nerve fibres themselves (at any rate as a rule), but merely a separation of the compound nerve cord. In the finest branches, however, the nerve fibres themselves may divide; the division, which always takes place at a node, is generally dichotomous—that is, one fibre divides into two, each of these again into two, and so on. These finest branches consisting of one or two nerve fibres, or of one only, with a very delicate perineurial envelope (Fig. 110, E. *c*), pass to some single muscle fibre, and each nerve fibre applies itself to the outer surface of the sarcolemma. At this point, if it has not done so before, the medulla disappears, the neurilemma becomes continuous with the sarcolemma, and the neuraxis passes into a disc of protoplasmic substance containing many nuclei, which is interposed between the striated muscle substance and the sarcolemma at this point, thus forming what is called a *motor plate* or end-plate.[1] Before ending the neuraxis divides and its divisions anastomose freely, but the exact relations of the various parts of the end-plate to the muscle-substance have not yet been clearly made out. The whole appears to constitute an apparatus

[1] This is the arrangement in most vertebrated animals. In the frog the neuraxis branches out without entering a distinct motor or end-plate.

by which the molecular disturbances of the substance of the neuraxis (the essential part of the nerve) may be efficiently propagated to the substance of the muscle.

42. If, instead of following the motor nerve to its distribution in the muscle, we trace it the other way, towards the spinal cord, we shall find no alteration of any moment until we arrive at the point at which the anterior root enters the cord. From the finest branches of the motor nerve (in which, as has been stated, the nerve fibres themselves divide) to this point of entry each nerve fibre extends ensheathed as one continuous undivided neuraxis in a long succession of internodal segments. At the point of entry into the cord the perineurium passes into the pia mater and the general connective tissue framework of the cord. The neurilemma and the nodes disappear. Often the neuraxis can be traced towards the anterior horn of the grey matter, invested only by a sheath of medulla which gradually becomes thinner and thinner until at length it disappears, and the fibre, thus reduced to its neuraxis, passes into one of the processes of one of the large *nerve cells*, which lie in the anterior cornu of the grey matter (Lesson XI. § 5).

These nerve cells are large, the body of the cell having a diameter varying from 50μ to 100μ or more. Each cell, *n*, contains a large clear nucleus (Fig. 111) in which lies a rounded *nucleolus*, *n'*; the protoplasmic body of the cell gives off (1) a variable number of *ramified processes*, *p*, which branch out in all directions into filaments of such extreme tenuity that their terminations cease to be traceable, and (2) a single *simple process*, *n p*, which becomes continuous with the neuraxis of a motor nerve fibre.

The neuraxis of a motor nerve fibre, therefore, is an extremely fine connecting thread or *commissure* materially continuous at its central end into a *nerve cell*, and at its peripheral end into a *muscle cell*; in other words, these are the central and peripheral end-organs of the fibre.

43. With one or two exceptions sensory nerve fibres are not distinguishable by any structural character from motor nerve fibres. Wherever special-sense organules exist the sensory fibres are connected with them by

means of their neuraxis, from which the neurolemma and medulla have disappeared.

In the case of the spinal nerves the sensory fibres are collected into the posterior roots, and pass through the ganglia of those roots. The ganglion consists of nerve fibres and nerve cells embedded in a framework of connective tissue which is continuous with the perineurium of the nerve. Each nerve cell (Fig. 112) consists like a nerve cell of the spinal cord, of a large nucleus, with a nucleolus, and of a cell body ; but the cell body is, in most cases at all events, prolonged into one process only, so

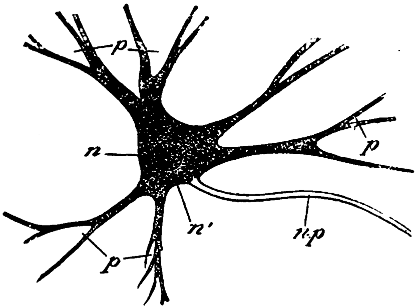

FIG. 111.—A LARGE NERVE CELL FROM THE ANTERIOR CORNU OF THE SPINAL CORD.

n, nucleus; *n'*, nucleolus; *p*, branched processes, the fine endings are cut away; *n p*, unbranched process, continued into the neuraxis of a motor fibre.

that the whole cell is pear-shaped. This process surrounded by a neurilemma, which is a prolongation of a sheath enveloping the cell, soon acquires a medulla, and thus becomes a nerve fibre, which then divides into two fibres, one of which may be traced into the nerve trunk, and the other along the posterior root to the spinal cord. Hence the nerve cells of the ganglion appear to be lateral appendages of the nerve fibres, forming a junction with them after the fashion of a T-piece. On the central side of the ganglion the fibres continue their course into the substance of the spinal cord towards the posterior cornu.

Like the motor fibres they lose their noded neurilemma, but their ultimate fate is not certainly made out.

44. The fibres just described, whether motor or sensory, are often spoken of as *medullated*, because except at their peripheral and central terminations they possess the characteristic medulla. Scattered among these medullated fibres in the spinal and cranial nerves, and very abundant in the sympathetic nerves, are fibres, which are often spoken of as non-medullated, because they possess no medulla. These are pale flattened bands, about as

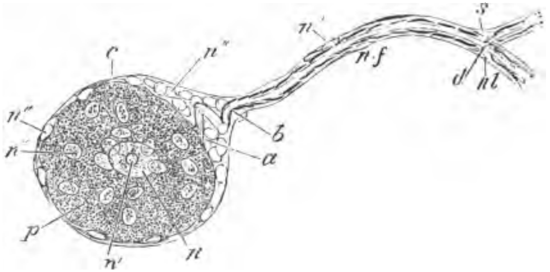

FIG. 112.—A NERVE CELL FROM THE GANGLION ON THE POSTERIOR ROOT OF A SPINAL NERVE.

n.c. the nerve cell, with *n*, nucleus, *n'*, nucleolus, *p*, protoplasmic body; *c*, capsule of the nerve cell; *n''*, nuclei of the capsule; *n.f.* the nerve fibre which, at the node, *d*, divides into two. At *a* the neuraxis of the fibre is lost in the substance of the cell; at *b* it acquires a medulla; at *n'''* nuclei are seen on the fibre. At the division the neuraxis *d* is seen to dlvide, and besides the neurilemma, *n.l.*, the fibre has an additional sheath, *s*, continuous with the capsule of the nerve cell.

wide as small medullated fibres, often fibrillated longitudinally, and frequently dividing. They appear, in fact, to be naked neuraxes, without medulla, and apparently without a neurilemma, though they bear at intervals nuclei which may represent the internodal nuclei of ordinary nerve fibres.

In the sympathetic ganglia are found nerve cells with several processes, one or more of which may be traced into such non-medullated fibres.

45. The spinal cord consists of: *a*, a connective-tissue

case well supplied with vessels and continuous with the perineurium of the nerves. This is called the *pia mater*, and from it delicate partitions proceed inwards towards the centre of the cord; *b*, a framework of a peculiar reticulated modification of connective tissue, termed *neuroglia*, which fills up the intervals between the partitions and bounds the cavities in which, *c*, the nerve fibres and nerve cells lie; and finally of, *d*, the epithelial cells lining the *central canal*, which extends from one end of the cord to the other.

The brain contains substantially the same elements as the cord, of which it may be regarded as a sort of expansion, the ventricles of the brain (all but the fifth)

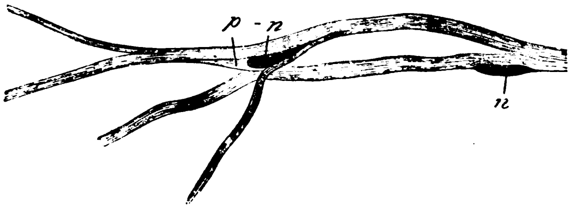

FIG. 113.—PALE NON-MEDULLATED FIBRES FROM THE PNEUMOGASTRIC NERVE.

n, nucleus; *p*, protoplasm belonging to the nucleus.

representing the dilated central canal. The disposition of the nerve cells and fibres, however, is extremely complicated, and cannot be dealt with here.

Two of the so-called "cranial" nerves require special notice. That which is commonly called the olfactory "nerve" is really a lobe of the brain and contains nerve cells. The proper olfactory nerves are bundles of fibres which proceed from the under surface of the above and traverse the cribriform plate to be distributed to the olfactory mucous membrane. And it is an extremely remarkable fact that these fibres closely resemble the non-medullated fibres of the sympathetic nerves, in being hardly anything more than neuraxes, bearing nuclei

at intervals. A sheath, apparently representing the neurilemma, is however present in each fibre.

The optic "nerve" is also properly speaking a lobe of the brain, and it retains its character as a part of the central nervous system in so far as its fibres have no neurilemma and are nodeless, but it contains no nerve cells along its course.

APPENDIX.

ANATOMICAL AND PHYSIOLOGICAL CONSTANTS.

THE weight of the body of a full-grown man may be taken at 154 lbs.

I. GENERAL STATISTICS.

Such a body would be made up of—

	lbs.
Muscles and their appurtenances	68
Skeleton	24
Skin	10½
Fat	28
Brain	3
Thoracic viscera	2½
Abdominal viscera	11
	147[1]

Or of—

	lbs.
Water	88
Solid matters	66

[1] The addition of 7 lbs. of blood, the quantity which will readily drain away from the body, will bring the total to 154 lbs. A considerable quantity of blood will, however, always remain in the capillaries and small blood-vessels, and must be reckoned with the various tissues. The total quantity of blood in the body is now calculated at about 1-13th of the body weight, *i.e.* about 12 lbs.

The solids would consist of the elements oxygen, hydrogen, carbon, nitrogen, phosphorus, sulphur, silicon, chlorine, fluorine, potassium, sodium, calcium (lithium), magnesium, iron (manganese copper, lead), and may be arranged under the heads of—

Proteids. Carbo-hydrates or Amyloids. Fats. Minerals.

Such a body would lose in 24 hours—of water, about 40,000 grains, or 6 lbs.; of other matters about 14,500 grains, or over 2 lbs.; among which of carbon 4,000 grains, or more than ½ lb.; of nitrogen 300 grains; of mineral matters 400 grains; and would part, per diem, with as much heat as would raise 8,700 lbs. of water from 0° to 1° Fahr., which is equivalent to 3,000 foot-tons.[1] Such a body ought to do as much work as is equal to 450 foot-tons.

The losses would occur through various organs, thus —by

	Water. grs.	Other Matter. grs.	N. grs.	C. grs.
Lungs	5,000	12,000	...	3,300
Kidneys	23,000	1,000	250	140
Skin	10,000	700	10	100
Fæces	2,000	800	40	460
	40,000	14,500	300	4,000

The *gains* and *losses* of the body would be as follows:—

		grs.
Creditor—	Solid dry food	8,400
	Oxygen	10,000
	Water	36,100
	Total	54,500
		grs.
Debtor—	Water	40,000
	Others Matters	14,500
	Total	54,500

[1] A foot-ton is the equivalent of the work required to lift one ton one foot high.

II. DIGESTION.

Such a body would require for daily food, carbon 4,000 grains, nitrogen 300 grains.

Now proteids contain, in round numbers, about 15 per cent. nitrogen, and 50 per cent. carbon, while carbo-hydrates and fats contain respectively 40 per cent. and 80 per cent. carbon. Hence the necessary amounts of nitrogen and carbon, together with the other necessary elements, might be obtained as follows :—

Proteids . . .	2,000 grs.	containing	300 grs.	nitrogen	1,000 grs.	carbon.
Carbo-hydrates	4,500	,,	,,	—	,,	1,800	,,
Fats	1,500	,,	,,	—	,,	1,200	,,
Minerals . .	400	,,	,,	—	,,	—	,,
Water . . .	36,100						
	44,500			300		4,000	

which, in turn, might be obtained, for instance, by means of—

		PROTEIDS. grs.	CARBO-HYDRATES.	FATS.
4,400 grs. very lean meat containing	25 p.c. proteids . . .	1,100	—	—
4,000 grs. bread containing	15 p.c. proteids . . . 60 p.c. carbo-hydrates	600	3,600	—
3,000 ,, potatoes ,,	2 p.c. proteids . . . 20 p.c. carbo-hydrates	60	600	—
6,000 ,, milk ,,	4 p c. proteids . . . 5 p.c. carbo-hydrates 4 c.c. fats	240	300	240
1,260 grains of fat, as fat of meat, butter, dripping, &c. . . .		—	—	1,260
36,500 grs. water	—	—	—	—
		2,000	4,500	1,500

This table, however, must be understood as being introduced for the sake of illustration only.

The fæces passed, per diem, would amount to about 2,800 grains, containing solid matter 800 grains.

III. CIRCULATION.

In such a body the heart would beat 75 times a minute, and probably drive out, at each stroke from each ventricle, from 5 to 6 cubic inches, or about 1,500 grains of blood.

The blood would probably move in the great arteries at a rate of about 12 inches in a second, in the capillaries at 1 to 1½ inches in a minute; and the time taken up in performing the entire circuit would probably be about 30 seconds.

The left ventricle would probably exert a pressure on the aorta equal to the pressure on the square inch of a column of blood about 9 feet in height; or of a column of mercury about 9½ inches in height; and would do in 24 hours an amount of work equivalent to about 90 foot-tons; the work of the whole heart being about 120 foot-tons.

IV. RESPIRATION.

Such a body would breathe about 17 times a minute.

The lungs would contain of residual air about 100 cubic inches, of supplemental or reserve air about 100 cubic inches, of tidal air 20 to 30 cubic inches, and of complemental air 100 cubic inches.

The vital capacity of the chest—that is, the greatest quantity of air which could be inspired or expired—would be about 230 cubic inches.

There would pass through the lungs, per diem, about 350 cubic feet of air.

In passing through the lungs, the air would lose from 4 to 6 per cent. of its volume of oxygen, and gain 4 to 5 per cent. of carbonic acid.

During 24 hours there would be consumed about 10,000 grains oxygen; and produced about 12,000 grains carbonic acid, corresponding to 3,300 grains carbon. During the same time about 5,000 grains or 9 oz. of water would be exhaled from the respiratory organs.

In 24 hours such a body would vitiate 1,750 cubic feet of pure air to the extent of 1 per cent., or 17,500 cubic feet of pure air to the extent of 1 per 1,000. Taking the amount of carbonic acid in the atmosphere at 3 parts, and

in expired air at 470 parts in 10,000, such a body would require a supply per diem of more than 23,000 cubic feet of ordinary air, in order that the surrounding atmosphere might not contain more than 1 per 1,000 of carbonic acid (when air is vitiated from animal sources with carbonic acid to more than 1 per 1,000, the concomitant impurities become appreciable to the nose). A man of the weight mentioned (11 stone) ought, therefore, to have at least 800 cubic feet of well-ventilated space.

V. Cutaneous Excretion.

Such a body would throw off by the *skin*—of water about 18 ounces, or 10,000 grains; of solid matters about 300 grains; of carbonic acid about 400 grains, in 24 hours.

VI. Renal Excretion.

Such a body would pass by the *kidneys*—of water about 50 ounces; of urea about 500 grains; of other solid matters about 500 grains, in 24 hours.

VII. Nervous Action.

A nervous impulse travels along a nerve at the rate of about 80 feet in a second in the frog, and of about 100 feet a second in man; but the rate in man varies very much according to circumstances.

VIII. Histology.

The following are some of the most important histological measurements:—

Red blood-corpuscles, breadth $\frac{1}{3200}$th of an inch, or 7 μ to 8 μ.

White blood-corpuscles, breadth $\frac{1}{2500}$th of an inch, or 10 μ.

Striated muscular fibre (very variable), breadth $\frac{1}{400}$th of an inch, or 60 μ; length $1\frac{1}{2}$ inch, or 30 to 40 millimetres.

Non-striated muscular fibre (variable), breadth $\frac{1}{4000}$th of an inch, or 6 μ; length $\frac{1}{500}$th of an inch, or 50 μ.

Nerve fibre (very variable), breadth $\frac{1}{12000}$th to $\frac{1}{2000}$th of an inch, or 2 μ to 12 μ.

Nerve cells (of spinal cord) excluding processes, breadth $\frac{1}{500}$th to $\frac{1}{250}$th or more of an inch, 50 μ to 100 μ or more.

Fibrils of connective tissue, breadth $\frac{1}{25000}$th of an inch, or 1 μ.

Superficial cells of epidermis, breadth $\frac{1}{1000}$th of an inch, or 25 μ.

Capillary blood-vessels (variable), width $\frac{1}{3500}$th to $\frac{1}{2000}$th of an inch, or 7 μ to 12 μ.

Cilia, from the wind-pipe, length $\frac{1}{3000}$th of an inch, or 8 μ.

Cones in the yellow spot of the retina, width $\frac{1}{8000}$th of an inch, or 3 μ.

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